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COMPARISON OF THE BRITISH CLASS 60 TRACKWAY AND AM-2 MAT FOR BOMB DAMAGE REPAIR APPLICATIONS

Raymond S. Rollings

Air Force Weapons Laboratory
Kirtland Air Force Base, New Mexico

November 1975

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Final Report

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AM-2 and British Class 60 trackway are compared as surfacing materials for bomb damage repair of runways. Each mat was evaluated on the basis of its operational characteristics, performance under load, and dynamic effects on aircraft. A field test was conducted to gather data on the performance of each mat under load, and a computer code, TAXI, was used to calculate aircraft response to the mats. AM-2 showed marginally superior load capacity and aircraft response; however the operational characteristics of the Class 60 trackway are far superior to those of AM-2. Class 60 trackway was concluded to be a superior surfacing

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materials for bomb damage repair.

This report was prepared for the Air Force Weapons Laboratory. Captain Lawrence D. Hokanson was the former Project Officer-in-Charge. Lt. Raymond S. Rollings (DEZ) was the Laboratory Project Officer-in-Charge.

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INTRODUCTION

In recent years bomb damage repair (BDR) of runways has become an item of increasing importance. Recent Arab-Israli conflicts and the Turkish invasion of Cyprus demonstated that attacks against runways can effectively neutralize enemy aircraft. Modern, sophisticated aircraft generally require a high quality runway to operate, and this dependency, along with the increased use of hardened aircraft shelters to protect individual aircraft, has made the runway a natural target.

The United States Air Force BDR procedure is set forth in AFR 93-2 and is designed to repair three 750 pound bomb craters simultaneously. This procedure consists of filling the bomb craters with debris from the explosion, topping the upper 1-foot depth of the crater with select fill, and then capping the backfilled crater with an AM-2 repair patch (ref. 1). AFR 93-2 was developed from testing at Eglin AFB, Florida, in 1963 and 1965 (refs. 2 and 3) and at Tyndall AFB, Flordia, in 1973 (ref. 4). In August 1974 a series of field tests examined AFR 93-2 procedures in detail under various adverse conditions. Test 1 was the repair of a 750 pound bomb crater under adverse moisture conditions (saturated subgrade and rain); Test 2 was a nighttime repair of a 750 pound bomb crater; and Test 3 was the repair of four craters from 15 pound charges. This testing revealed certain deficiencies in AFR 93-2 and is discussed in detail in reference 5.

British forces use the Class 60 trackway in lieu of AM-2 in their BDR procedure. The trackway has certain advantages over AM-2 and potentially could simplify and improve AFR 93-2. This study examines the characteristics of the mats and their performance for BDR. A field test of AM-2 and trackway sections was conducted at Tyndall AFB in 1974, and the results were used with the computer code TAXI to evaluate the comparative performance of the mats. The field test provided information on the performance of the mats under load, while TAXI computed the dynamic response of aircraft to the mat profiles.

SECTION II

TRACKWAY AND AM-2 DESCRIPTION

AM-2 matting consists of extruded aluminum alloy panels which interlock to form a repair surface. Panels are 2 feet wide, either 6 or 12 feet long, 1.5 inches thick, and weigh 6 to 6.2 pounds/ft^2. Any size of repair surface can be fabricated, but the standard BDR patch is 54 feet wide and 77 feet 6 inches long and has 4 foot long ramps on the leading and trailing edges of the patch. This standard BDR patch can be assembled by a team of 17 well trained personnel in less than 1 hour (ref. 5). AFR 93-2 procedures using AM-2 matting have been extensively tested and are described in detail in references 2, 3, 4, and 5.

The British Class 60 trackway is composed of individual panels of an extruded aluminum alloy. Each panel interlocks with adjoining panels, and at the end of each panel, a sliding barrel bolt enters a slot in the adjoining panel to prevent sideways motion. The trackway panels are 9 inches wide, either 7.5 or 15 feet long, and weigh about 6.4 pounds/ft^2. Ramps for the trackway patch are only 6 inches long (figure 1). The standard repair patch is 52.4 feet wide and 36 feet long and can be assembled in 1 to 2 hours by 12 men (ref. 6).

Unlike AM-2, the trackway does not have to be assembled during the actual repair process. The narrow panels provide enough articulation to form an assembled patch into a roll with a minimum radius of about 27.5 inches (figure 2). Consequently, the trackway can be preassembled, rolled, and stored for immediate use. Two standard patches can be joined together to form the same size surface as the standard AM-2 patch and can be stored as a single roll. This roll will be 52.4 feet wide, have a 4.1 foot outer diameter, and weigh 27,315 pounds (ref. 6).

The capability for storing the trackway as a preassembled roll offers some unique operational advantages. Presently 51 men out of a 121 man team are used to assemble three AM-2 patches in the AFR 93-2 procedure. There is some conflict in the personnel requirements for the trackway. The most current reference states that a minimum of 20 men is required to unroll the mat (ref. 6) while an earlier report states that four men, and presumably

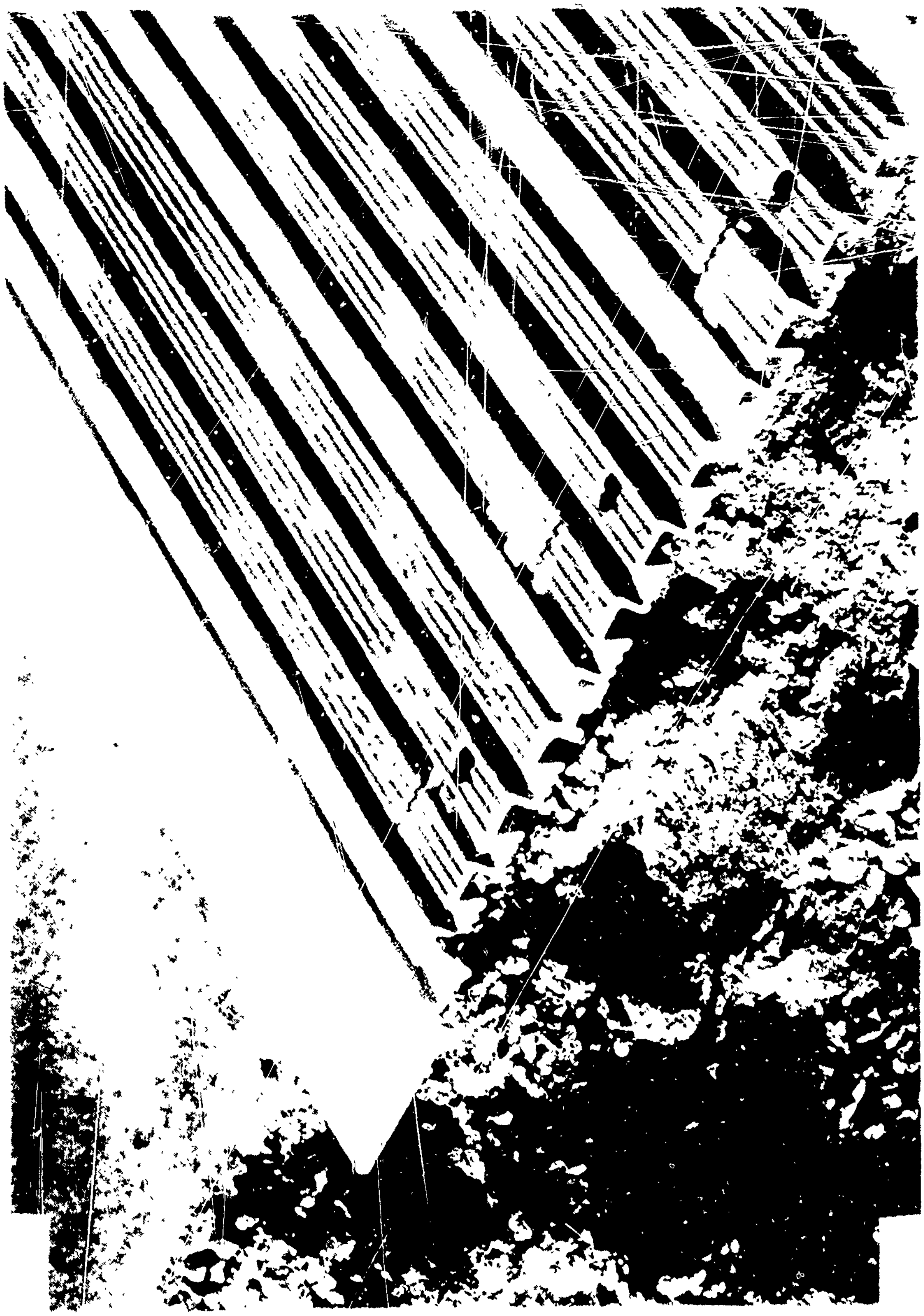


Figure 2. Rolls of Class 60 Trackway and Bomb Dollies for Transport

some unspecified equipment, required 15 minutes to unload the trackway roll, unroll it, and position it over the crater (ref. 7). In either case, the trackway requires fewer personnel than AM-2. In AFR 93-2, matting is not placed over the crater until 2 hours 45 minutes into the repair so that a single team of 20 members, along with the six laborers presently assigned to each of the craters, will have ample time to handle all three rolls of trackway.

The use of the Class 60 trackway in lieu of AM-2 is also expected to better utilize the existing BDR equipment. AFR 93-2 requires that three of the seven AC-645 front end loaders in the BDR package load the AM-2 on three lowboy trailers at the storage yard and then unload it at the three craters. After allowing 30 minutes for assembly of the equipment, the loaders cannot hope to finish with the AM-2 until 1 hour 20 minutes into the repair (ref. 5). Testing has shown that at least two loaders are needed at the stockpile, and with three loaders handling AM-2, only two loaders are available for work at the three craters.

These loaders can be used more efficiently with the Class 60 trackway. The British use a single rubber-tired Michigan 275 front end loader to load the trackway onto bomb dollies and tow it to the crater. The USAF BDR kit has only the smaller AC-645 front end loader. With a 0^{o} tipping load of 19,710 pounds, two AC-645 loaders will be required to load the trackway rolls. Specially built or converted trailers, such as the British bomb dollies, would have to be added to the equipment package, and ideally, the trackway could be unrolled directly from the trailers. Three 10 ton truck tractors, which are presently required by AFR 93-2 to haul the dozers and then the AM-2 to the craters could be used as prime movers to tow the trackway to the crater sites.

The British Class 60 trackway is compatible with the requirements of AFR 93-2 and offers some distinct operational advantages. A single matting team of no more than 20 men is capable of handling the trackway as compared to the three mat assembly teams of 17 men each which are now used with AM-2. Since only two loaders are needed to handle the trackway, one of the three loaders now used to handle AM-2 will be freed to work at the crater. If the trackway can be unrolled directly from the trailer, only 80 minutes of loader operating time will be spent handling the trackway, but if the trackway has

to be unloaded, this time increases to 140 minutes. In either case this is superior to the 150 minutes of loader operating time presently required by AFR 93-2 procedures. Since the trackway can be preassembled, one matting team and two loaders are able to handle all the matting tasks within the time allotted in AFR 93-2.

SECTION III

FIELD TEST

The field test of the Class 60 trackway was conducted on 20 November 1974 at Tyndall AFB, Flordia, to obtain data on the comparative performance of the trackway and AM-2 under load. The backfilled crater from Test 2 of the August 1974 BDR field tests (ref. 5) was leveled and used as the subgrade for the trackway and AM-2 mats. Because of grading operations and consolidation in the backfill, the repair surface for this test was superior to that of an actual expedient repair, but use of an actual repaired crater was desirable to ensure that the mats could be compared under the most realistic subgrade conditions available.

The subgrade for the mats consisted of 19 to 21 inches of select fill with good load carrying characteristics. This select fill was placed over a 750 pound bomb crater which had been backfilled with pavement debris and a sandy clay soil ejecta from the bomb explosion. This backfill varies widely in its properties but generally has poor load carrying capacity. Tables 1 and 2 present the results of various tests on the surface of select fill and debris backfill. Sand density tests were used to obtain the unit weights, and standard plate load tests were used to obtain the modulus of subgrade reaction (k). Table 2 presents data collected on the debris backfill from earlier testing in August 1974 (ref. 5). It is important to recognize that values for the debris backfill are only representative and can vary widely because the crater backfill consists of various sized pavement debris and soil ejecta which are pushed into the crater indiscriminately with little or no compactive effort.

The mats were trafficked with an F-4 load cart obtained from the U.S. Army Engineer Waterways Experiment Station (WES). Lead ingots were placed on the rear of the load cart to apply a simulated, single gear load to an F-4 tire. The tire was inflated to 267 PSI and had a contact footprint of 103.4 inches so that a load of 27.6 kips was applied to the mats. Figure 3 shows the load cart as it trafficks the Class 60 trackway. Neither mat was anchored and both were trafficked 100 times.

Table 1

SELECT FILL TEST RESULTS

	$\bar{x}$	s	Comment
Unit Weight (PCF)	145.6	6.2	3 Tests, 140.0 to 152.3 PCF
Moisure Content (%)	1.8	0.2	3 Tests, 1.6% to 2.0%
k, Modulus of Subgrade Reaction (PCI)	240	---	

$\bar{x}$ = Mean of Measurements

s = Standard Deviation

Table 2

DEBRIS BACKFILL TEST RESULTS
(All data obtained from Reference 5)

Unit Weight (PCF)	125.2
Moisture Content (%)	5.47
k (PCI)	73
CBR (Average of 3)	9.0

Since the north-south centerline of the crater had been used for load testing during Test 2 in August, the subgrade was already compacted in that area. To keep the testing of the mat over as much of the crater as possible and to use a subgrade that had not been compacted by earlier load testing, the line of travel of the load cart over the AM-2 and the trackway was off-set 3 feet from the crater centerline as shown in figure 4. Figure 5 shows the cross section of the backfilled crater under the line of travel of the load cart. Both elastic deflection (deflections under load) and residual deflections (deflection after load is removed) were measured. All measurements were made with a dumpy level and surveying rod (figure 6) and were read

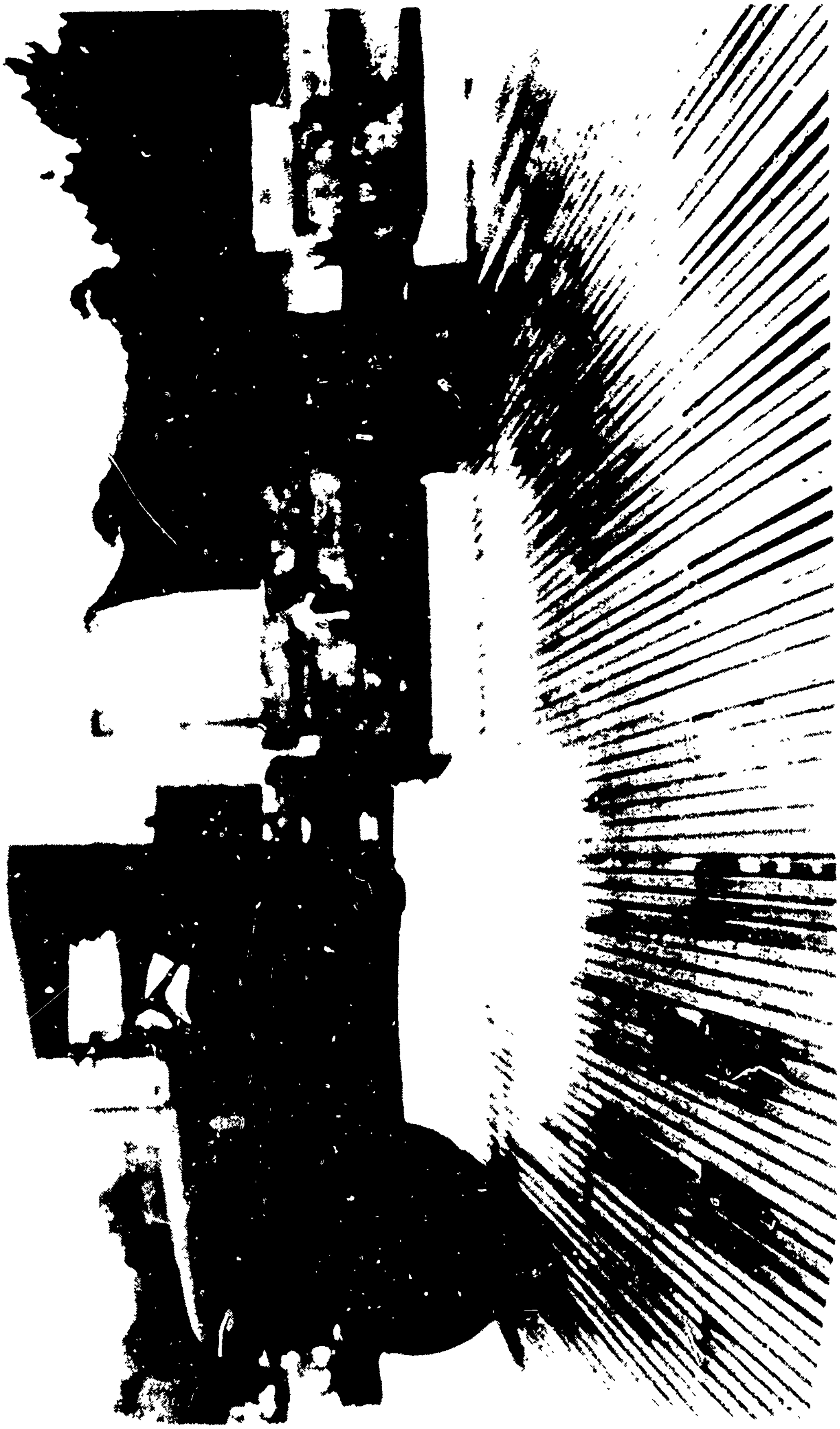


Figure 3. Trafficking the Trackway with the WES Load Cart

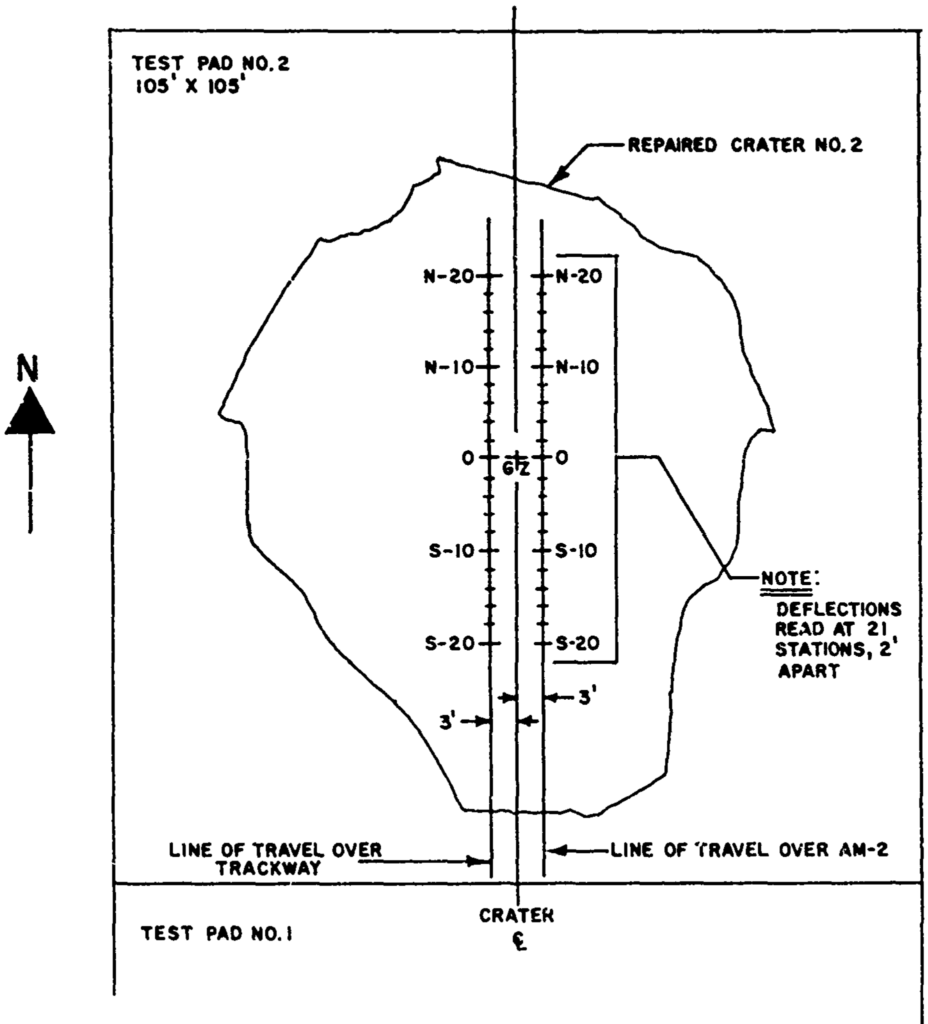
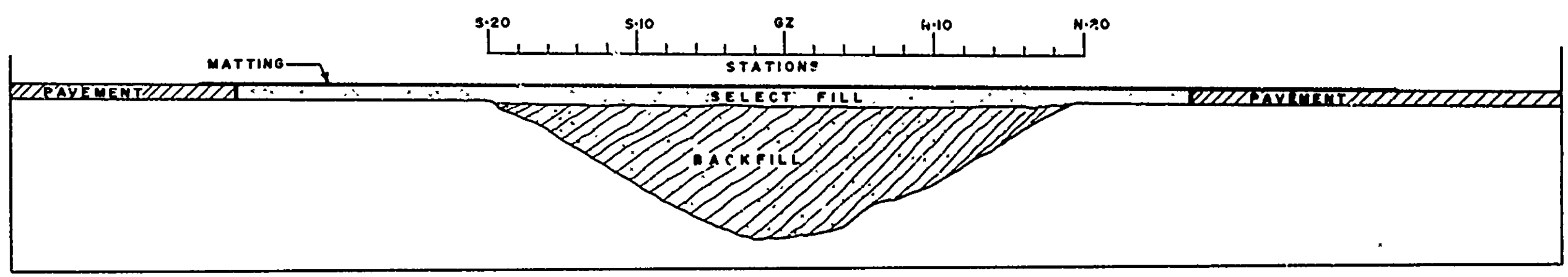


Figure 4. Test Site of Class 60 Trackway and AM-2 Mat



CRATER CROSS-SECTION

Figure 5. Cross Section of the Backfilled Crater

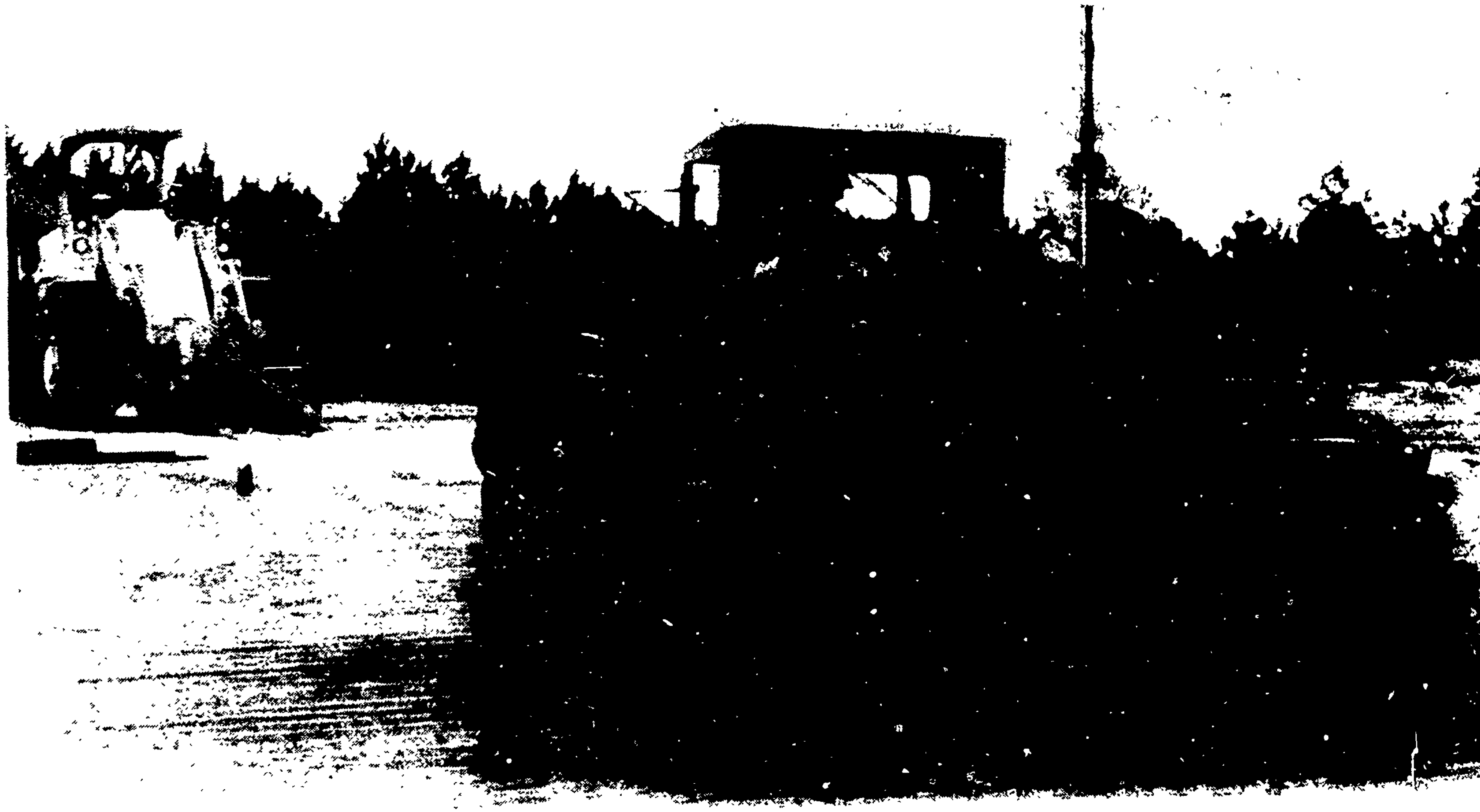


Figure 6. Reading Deflections on the Trackway

to the nearest hundredth of a foot. Other methods of measuring deflections such as the Benkleman Beam have been tried in previous tests but were unsatisfactory because of the large rotations at the edge of each panel of matting. Deflections were measured at 21 stations 2 feet apart, as shown in figures 4 and 5.

A patch of the British trackway was assembled and towed over the crater for testing on the morning of 20 November 1974. No problems were encountered in the assembly of the trackway by the Air Force Civil Engineering Center personnel, and the patch was easily towed into place (figure 7). After load testing, the trackway was removed, and a patch of AM-2 was positioned and load tested.

The data gathered from the field test consisted of elevations and deflections of AM-2 and Class 60 trackway under various loading conditions. Table 3 presents the results of the load testing. This table shows the average deflection measured at all 21 stations, as well as the maximum and minimum deflection. The average deflections are plotted in figure 8; and figures 9 to 12 compare the profiles of the trackway and AM-2 at various points during the loading cycles.

The deflections shown for AM-2 in table 3 and on figure 8 for the 50th pass are believed to be incorrect. A review of the survey notes for that pass showed some obvious inconsistencies. Elevations of certain points under load were found to be 0.01 foot higher than they were 25 passes earlier. A human error in positioning the rod on the load cart or some similar problem may have resulted in the elevations for the 50th pass being too high.

From figures 8 to 12 it is obvious that the Class 60 trackway deflects more than AM-2. This larger deflection is not surprising, considering that a 2 foot by 12 foot panel of AM-2 will act more like a rigid plate than will the 9 inch by 12 foot trackway panels. In figure 8 the rate of deflection increase for the AM-2 and trackway is about equal after the 50th pass. The AM-2 mat shows very little change in residual deflection after the initial deflection, as can be seen in figures 8, 9, and 12. For deflections as small as the ones in this test, the mat will not conform to the contour of the subgrade but instead will bridge over small voids. The Class 60 trackway shows a similar tendancy in figure 8, but it is less pronounced.

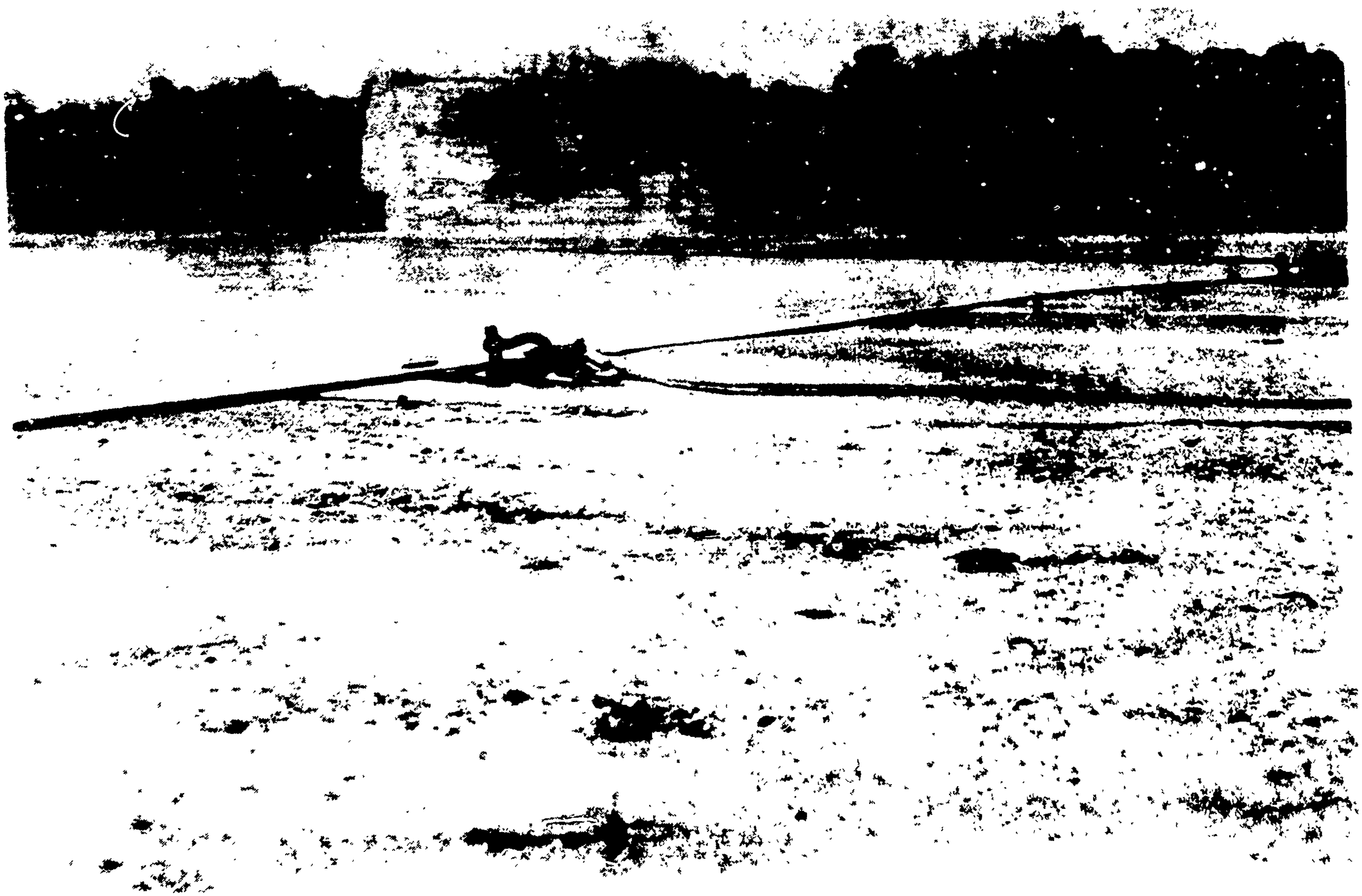


Figure 7. Towing Attachments for the Trackway

Table 3

RESULTS OF LOAD TESTING

	DEFLECTION (ft)							
	Class 60				AM-2			
	$\overline{X}$	s	Max.	Min.	$\overline{X}$	s	Max.	Min.
1. 1st Pass Under Load	0.039	0.012	0.06	0.02	----	----	----	----
2. After 1st Pass	.015	.007	.03	.00	----	----	----	----
3. 3rd Pass Under Load	----	----	----	----	0.016	0.009	0.03	0.00
4. After 3rd Pass	----	----	----	----	.010	.005	.02	.00
5. 25th Pass Under Load	.058	.014	.09	.04	.020	.010	.04	.00
6. 50th Pass Under Load	.061	.013	.09	.04	.018	.011	.03	.01
7. After 50th Pass	.027	.007	.04	.01	.011	.005	.02	.00
8. 75th Pass Under Load	.068	.013	.09	.05	.028	.008	.04	.01
9. After 75th Pass	.028	.007	.04	.01	.017	.005	.02	.01
10. 100th Pass Under Load	.065	.012	.09	.05	.033	.012	.05	.01
11. After 100th Pass	.028	.007	.04	.01	.014	.005	.02	.01

$\overline{X}$ = Mean of Deflections

s = Standard Deviation

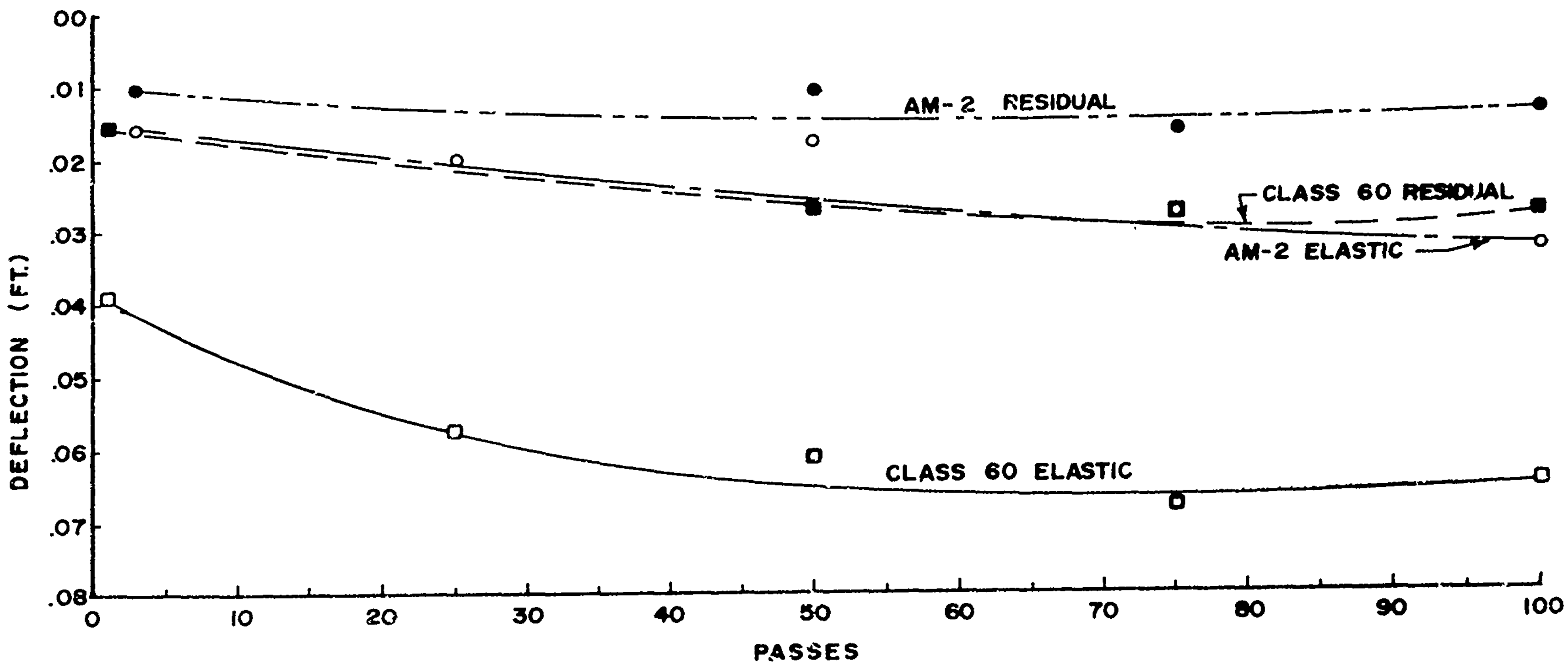


Figure 8. Deflections of Class 60 and AM-2 Mat

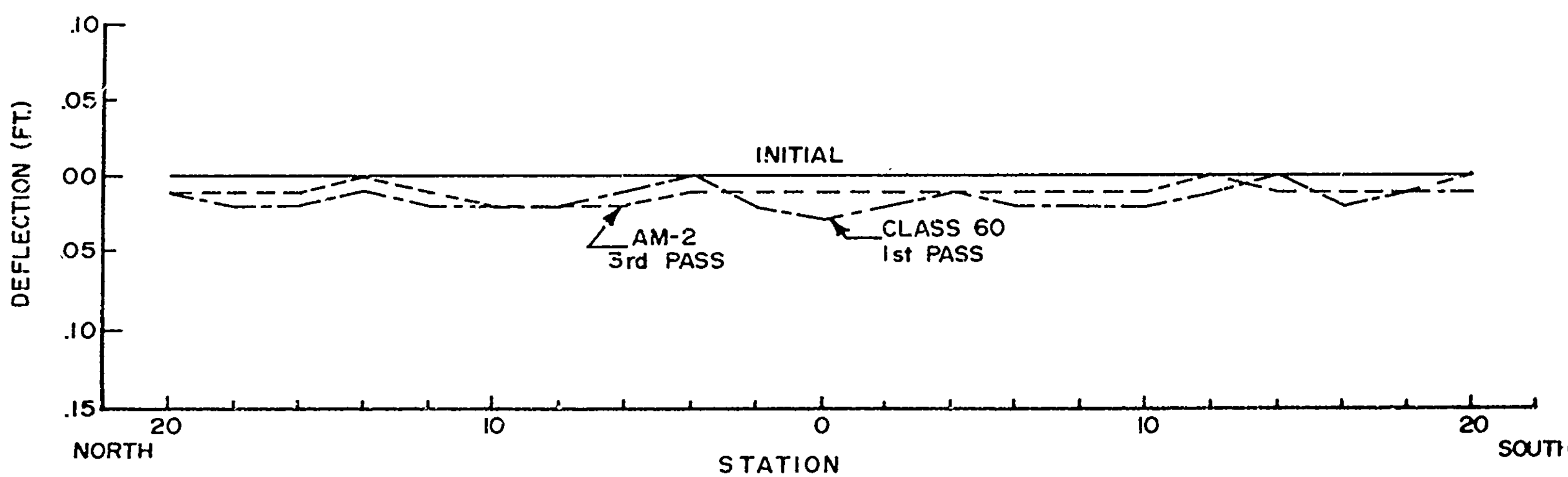


Figure 9. Comparison of Residual Deflection 1st Pass (Class 60) and 3rd Pass (AM-2)

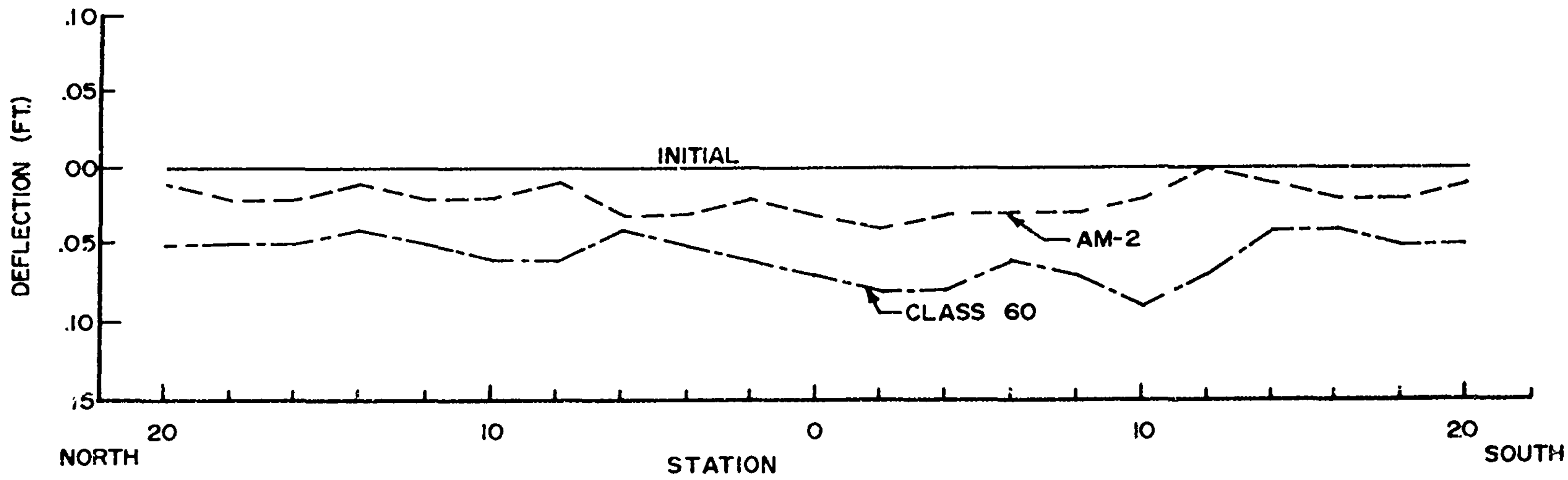


Figure 10. Comparison of Elastic Deflection on 25th Pass

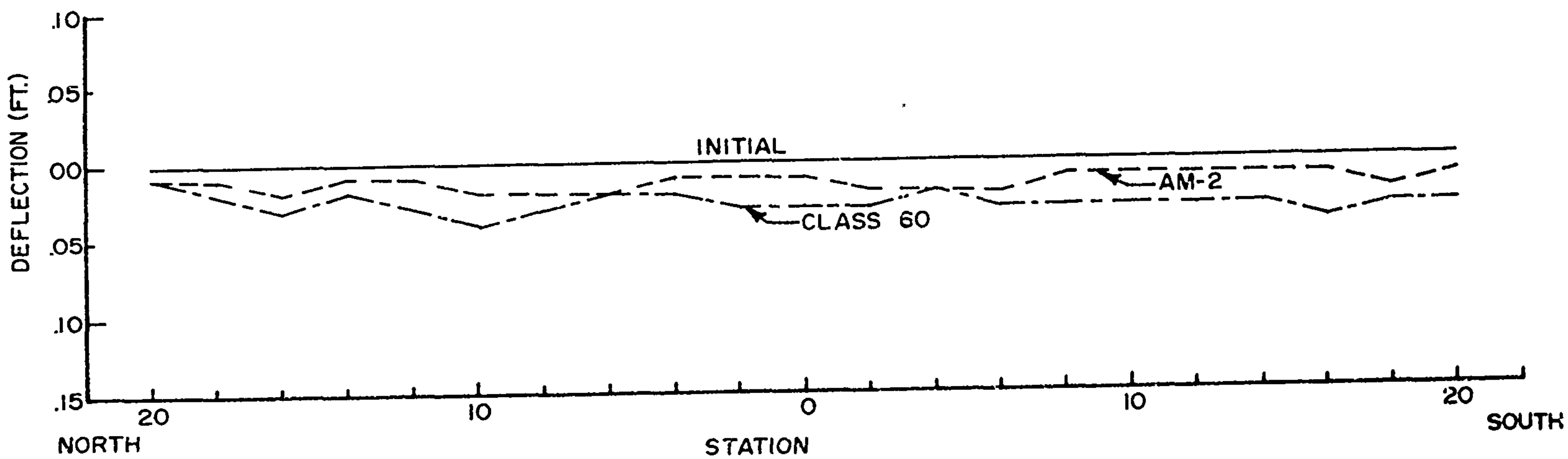


Figure 11. Comparison of Residual Deflection on 100th Pass

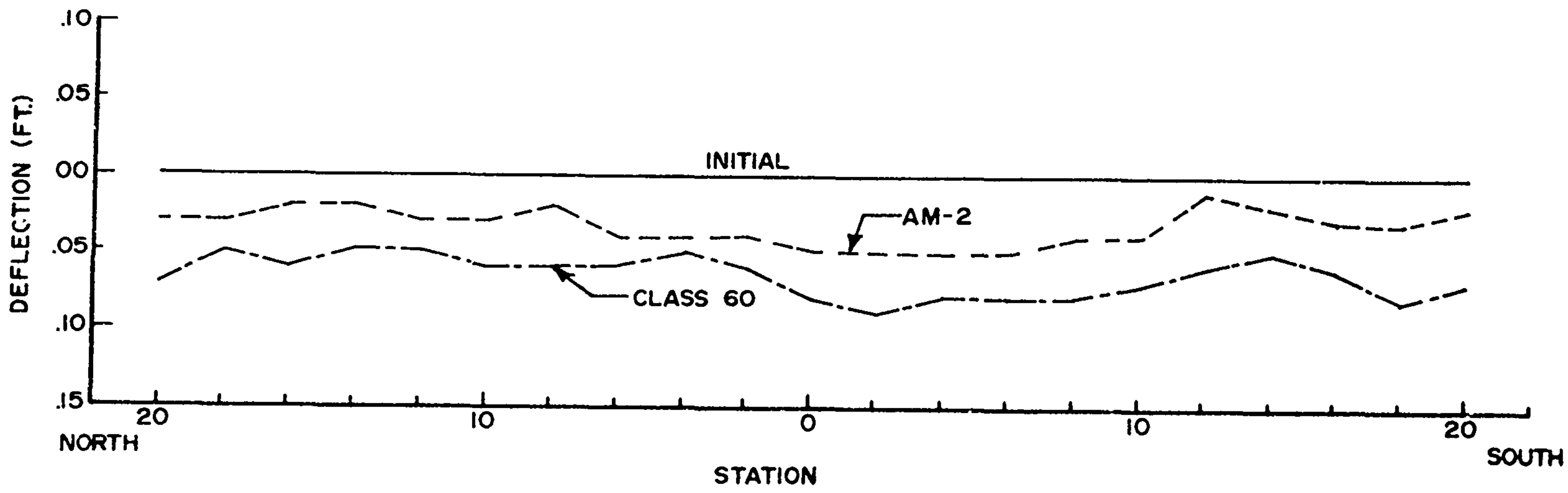


Figure 12. Comparison of Elastic Deflection on 100th Pass

When the trackway was towed from the crater after 100 cycles of loading, the subgrade cleary showed the imprint of the load cart passing over the trackway (figure 13). After the AM-2 was removed, there was also a visible compacted path but not to the extent of the trackway.

The magnitude of deflections in the test was universally small. The maximum deflection recorded was only 0.09 feet. These small deflections and the leveling out of average deflections shown in figure 4 indicate that neither matting system was approaching failure after 100 loads on this subgrade condition.

As expected, the AM-2 mat had smaller deflections than the Class 60 trackway, but neither mat approached failure. Both AM-2 and trackway can be used as surfacing for backfilled bomb craters without their undergoing excessive deflection or failure. The results of the load testing suggest that AM-2 is capable of sustaining more cycles of load and will perform adequately on poorer subgrades than will the trackway, but the higher load capacity of AM-2 cannot be fully utilized since the number of loading cycles will be limited in an expedient repair.

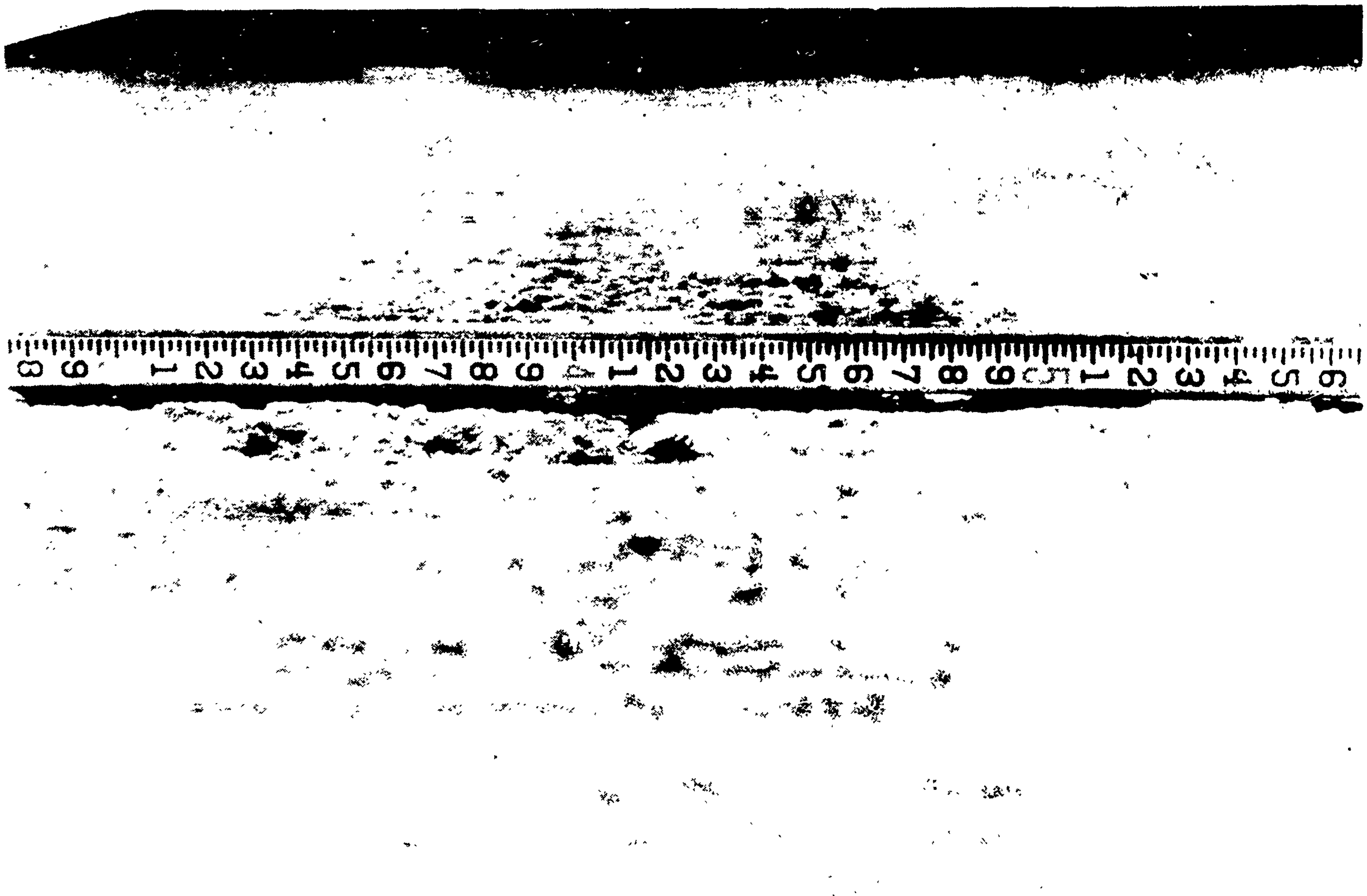


Figure 13. Rutting under the Trackway

SECTION IV

DYNAMIC ANALYSIS

TAXI, a computer code developed by the Air Force Flight Dynamics Laboratory, uses a general airplane/runway mathematical model with up to 15 structural modes of vibration to simulate an aircraft traversing a rigid runway profile. Individual aircraft characteristics and a runway profile are used as input and the code calculates the main gear stroke, nose gear stroke, main gear force, nose gear force, distance down the runway, tail acceleration, center of gravity acceleration, pilot station acceleration, and simulation time at 0.01 or 0.02 second intervals. The calculated aircraft responses have agreed well with those measured on instrumented aircraft on standard runways (ref. 8). This code was used to evaluate the response of a simulated F-4 weighing 58,000 pounds crossing Class 60 trackways and AM-2 mats at a given velocity of 45 fps. Because of the interaction of lift, velocity, and weight in the code, the maximum aircraft response parameters for this particular aircraft and loading condition appear to occur around 45 fps (ref. 9). This is also within the range of velocities verified by operation of an instrumented RF-4C over an AM-2 patch (ref. 10).

Four profiles were selected for comparing the aircraft response to the AM-2 and trackway mats. A 42 foot wide crater in a smooth runway was assumed to be covered with 1.5 inch thick mat which was anchored at either end of the crater. The profile of the mat on each of the four runs conformed to the loaded profile of the Class 60 trackway on the 1st and 100th pass and the AM-2 on the 3rd and 100th pass. Four foot ramps were used for the AM-2, and 6 inch ramps were used for the trackway. The runway profile as encountered by the nose gear for each of the runs is shown in figures 14 to 17.

Each element of roughness in the mat causes a response in the aircraft. This response will vary depending on aircraft properties such as speed, weight, damping characteristics, and natural frequency. The individual responses of each element of roughness in the mat will combine to reinforce and magnify the aircraft response or will interfere destructively and reduce the aircraft response. Obviously any change in the length of the mat or in deflections will change the responses in the aircraft; and the response may

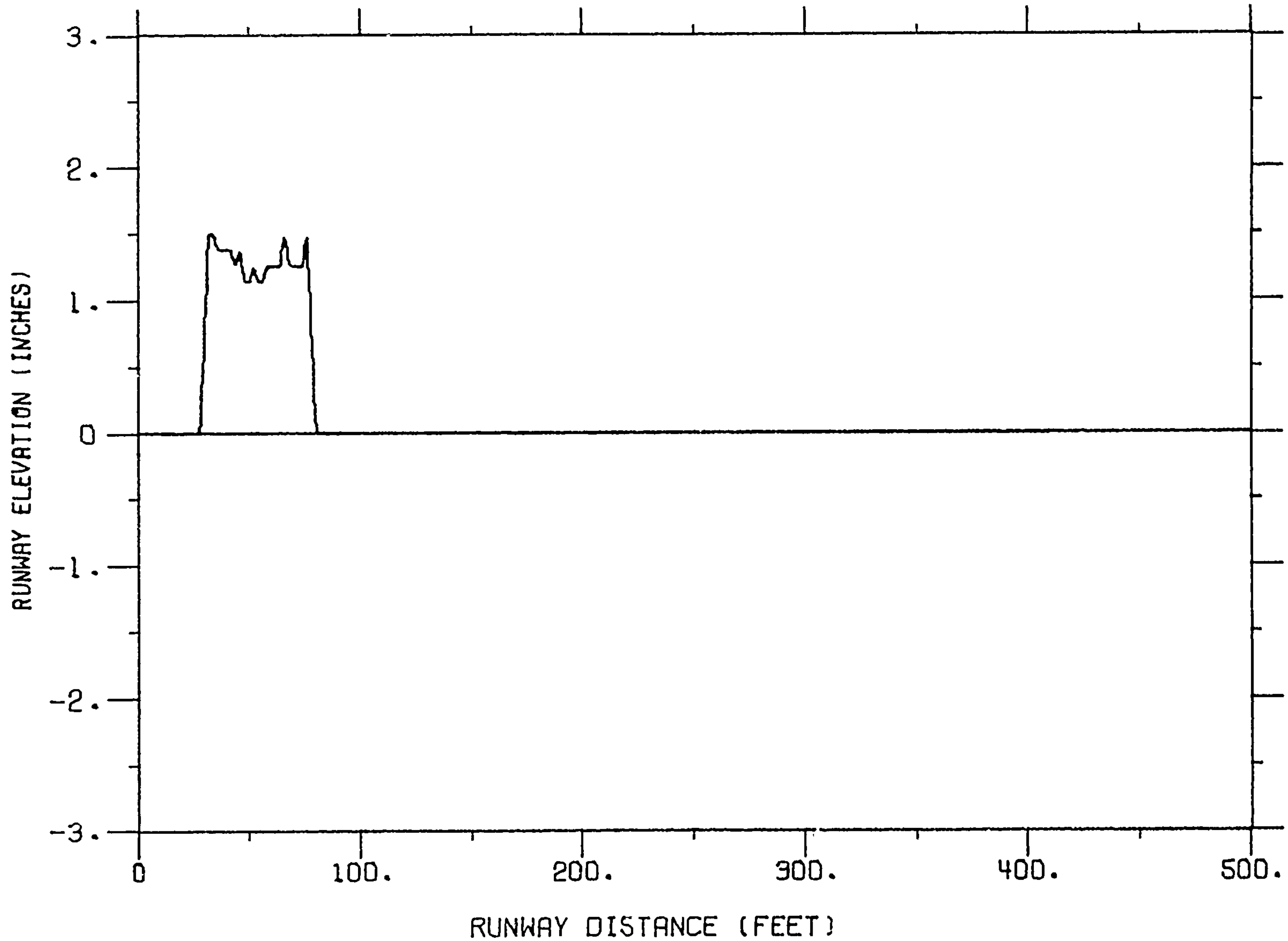


Figure 14. Nose Gear Track, AM-2 3rd Pass

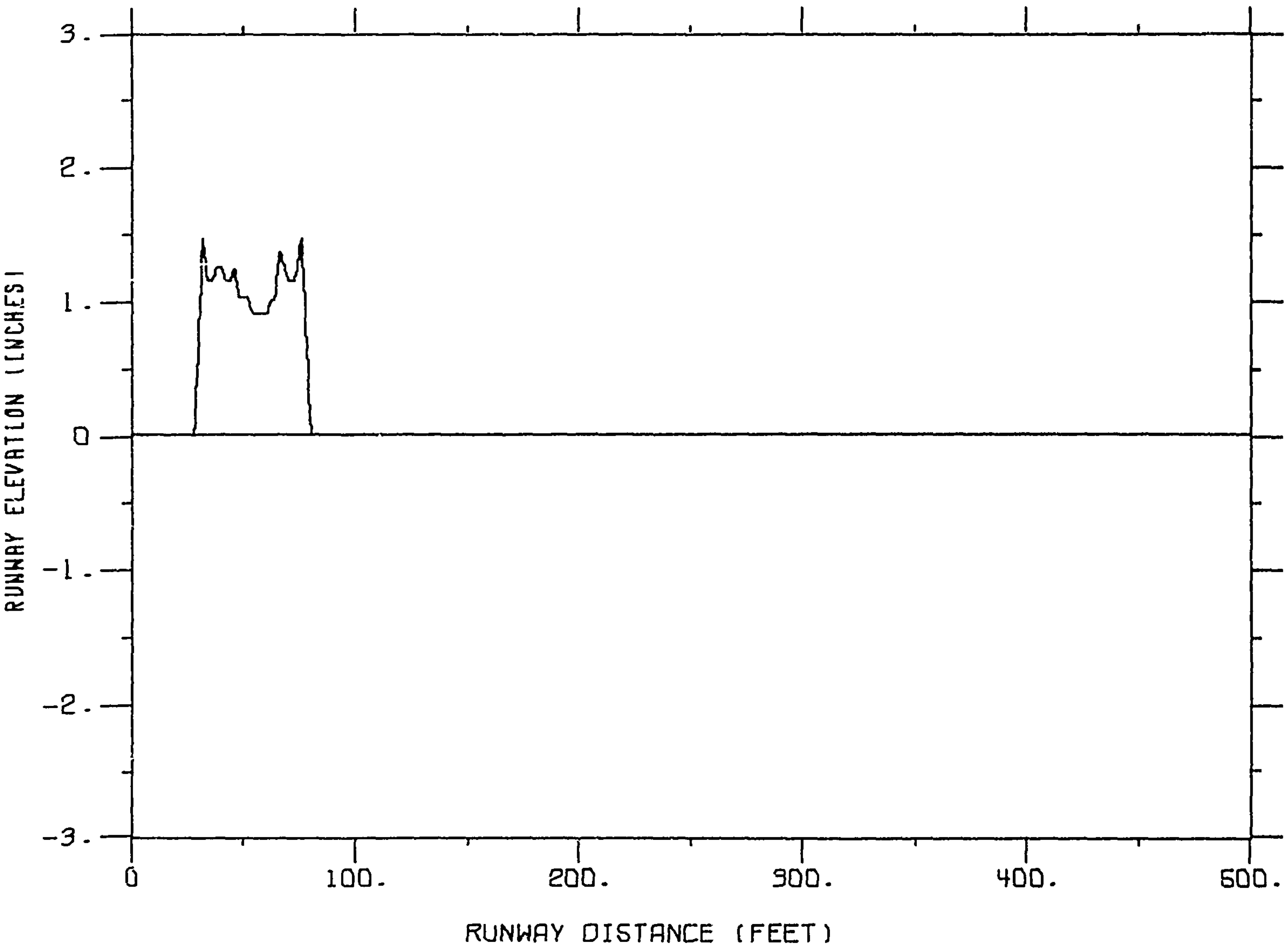


Figure 15. Nose Gear Track, AM-2 100th Pass

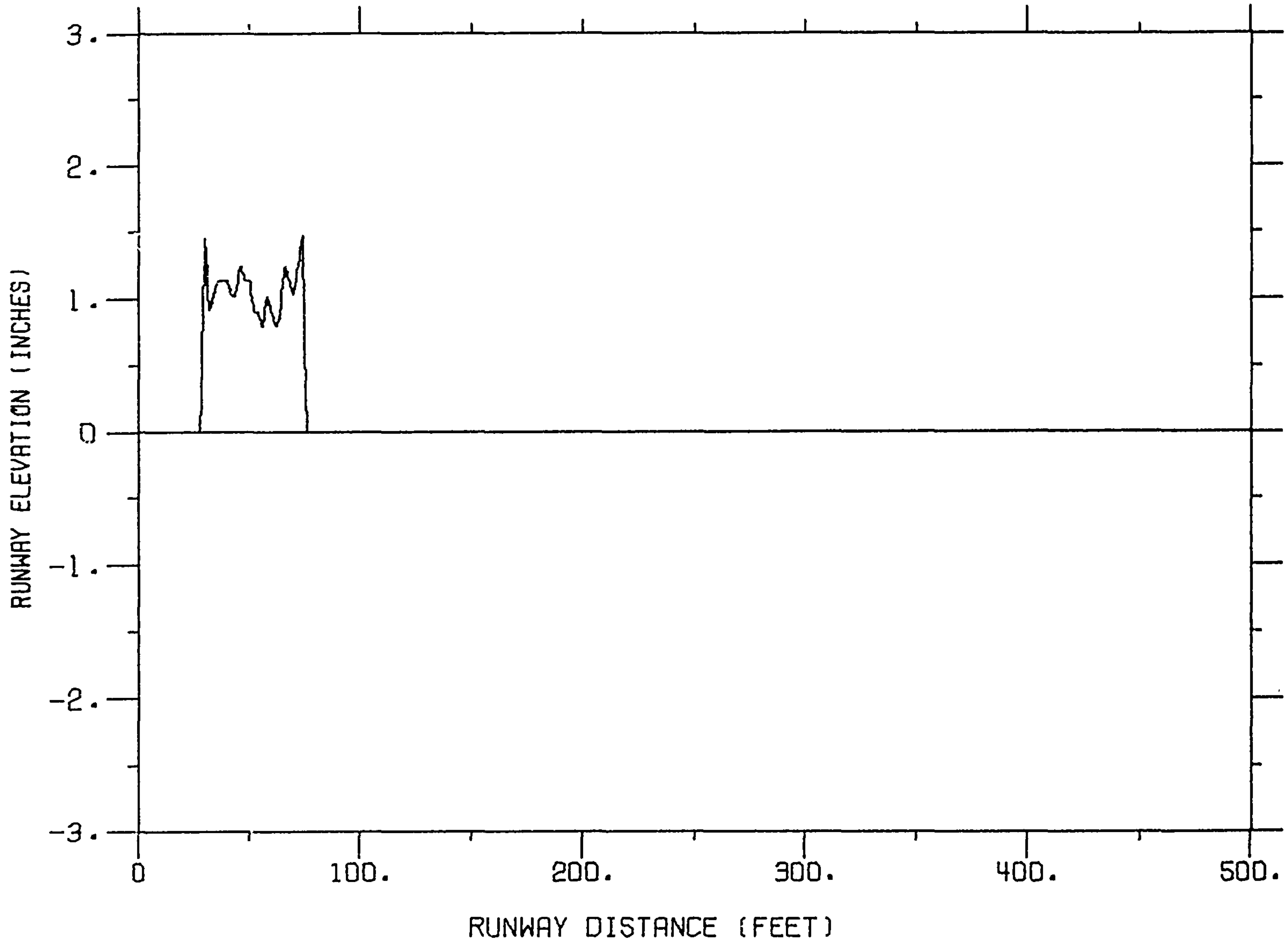


Figure 16. Nose Gear Track, Trackway 1st Pass

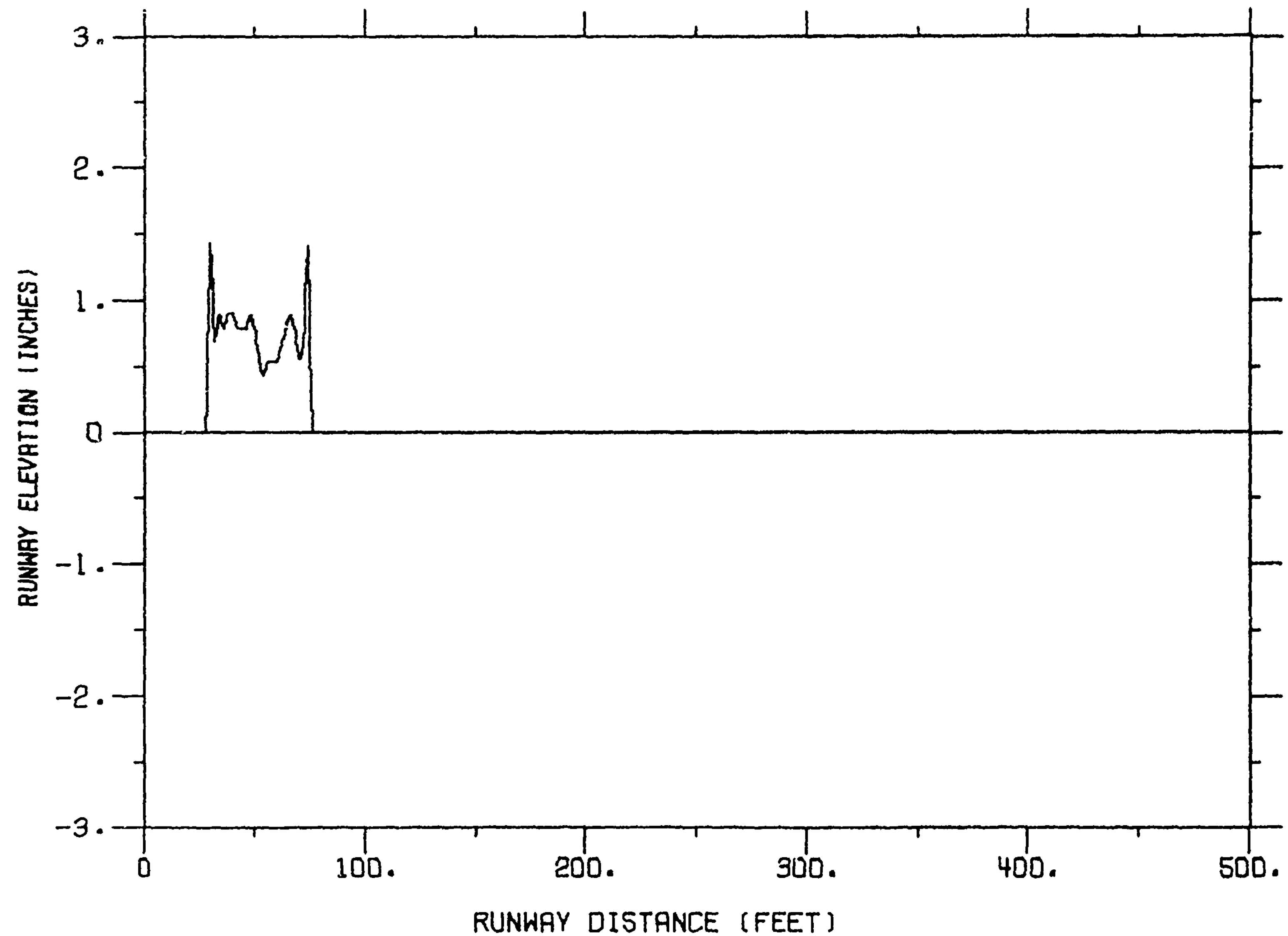


Figure 17. Nose Gear Track, Trackway 100th Pass

either increase or decrease depending on whether destructive interference or positive reinforcement takes place. The purpose of this study is to examine the comparative response of an F-4 to typical trackway and AM-2 mat profiles. Varying number of mats, deflection of the mats, or aircraft properties will change the aircraft response.

Table 4 shows the maximum calculated values of aircraft response for each of the four profiles, and the plots of each parameter along the runway length are presented in the appendix. Gear forces showed very little variation and were within 8 percent of each other. AM-2 generated consistently lower positive accelerations at the tail, negative accelerations at the pilot station, and both positive and negative accelerations at the aircraft center of gravity. Values for aircraft response over the AM-2 profiles tended to be slightly superior to the trackway, but the difference is negligible.

Currently there are no roughness critera for BDR. Accelerations at the pilot station for both mats were above the commonly used limit of 0.4 g, but this is a limit for crew comfort and is not meant to apply to the emergency conditions inherent in BDR. Figure 18 is taken from reference 11 and establishes human limits for vertical accelerations at various frequencies. Plotted on this figure are the accelerations at the pilot station for the four profiles. Frequency and acceleration are taken from the harmonic response and are not the maximum accelerations. The plots of response parameters versus aircraft distance along the runway can be found in the appendix to this report. The tolerance limit plotted in figure 18 is for exposures lasting 5 to 20 minutes, but young, physically fit subjects can be expected to tolerate short exposure beyond this limit (ref. 11). The short-time tolerance limit is the limit at which soft tissue damage occurs in a relatively short time (ref. 11). From the plot of the four points in figure 18, it appears that accelerations generated by the four profiles of the AM-2 and trackway are well within acceptable limits.

The dynamic response of simulated F-4 showed very little difference between the AM-2 and trackway mats. AM-2 had a slight tendancy to give superior response parameters but not of sufficient magnitude to be significant. There is a general lack of criteria for BDR roughness, but judging from existing criteria, the aircraft response on both mats was within tolerable limits.

Table 4

MAXIMUM CALCULATED VALUES OF AIRCRAFT RESPONSE

Mat Profile	Force (Kips) Main Gear	Force (Kips) Nose Gear	Acceleration (g) Tail +	Tail -	Center of Gravity +	Center of Gravity -	Pilot Station +	Pilot Station -
Class 60 - 1st Pass	71.7	15.5	2.02	1.29	0.60	0.44	0.52	0.50
Class 60 - 100th Pass	71.8	14.7	2.12	1.65	0.68	0.57	0.56	0.56
AM-2 - 3rd Pass	71.7	16.0	1.49	1.49	0.41	0.37	0.53	0.36
AM-2 - 100th Pass	67.3	15.9	1.19	1.29	0.33	0.30	0.49	0.38

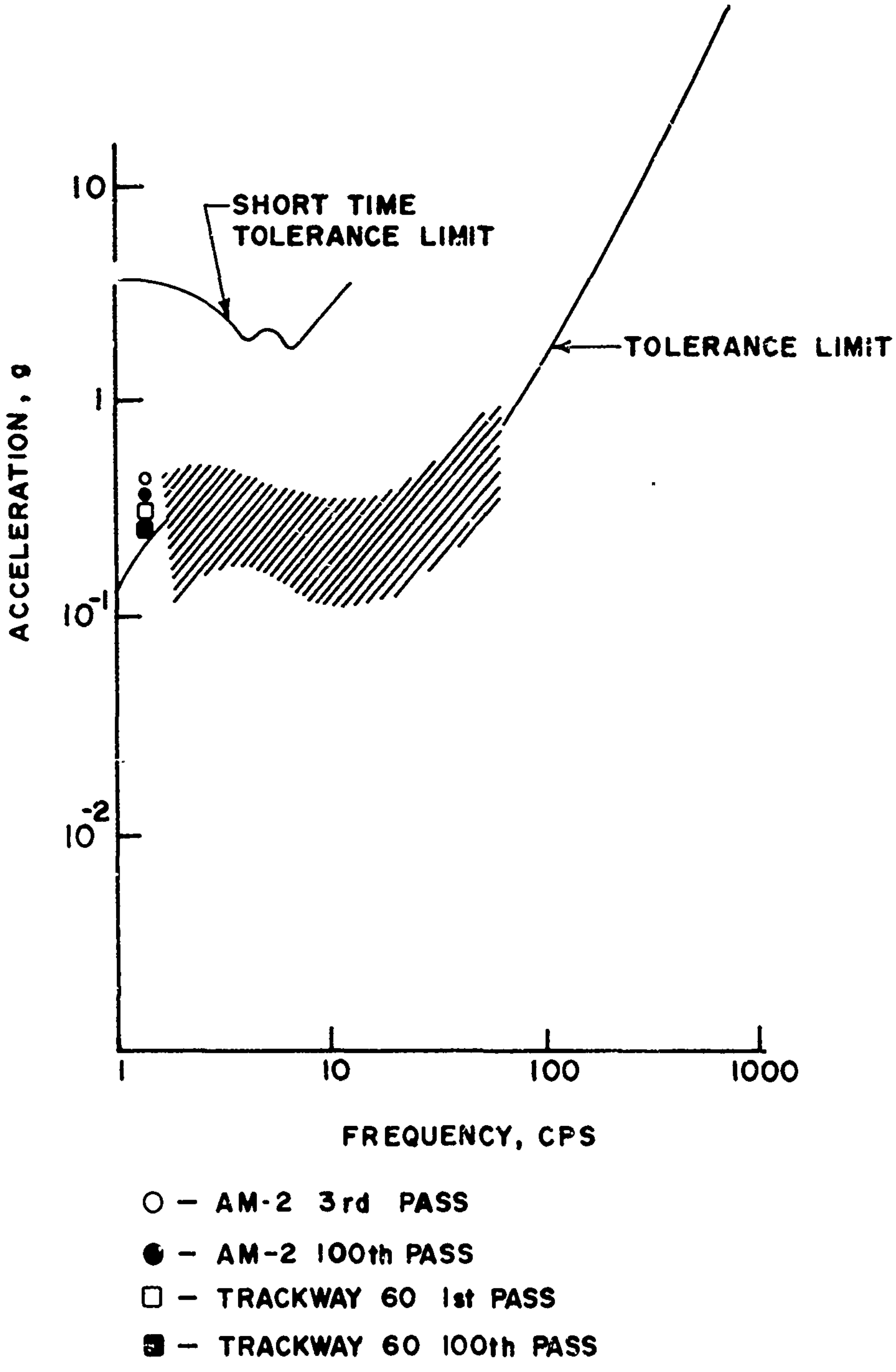


Figure 18. Vibration Limits

SECTION V

CONCLUSIONS

As summarized in figure 19, the Class 60 trackway is superior to AM-2 for a BDR crater surfacing. AM-2 showed better performance under load and marginally superior dynamic aircraft response values; however, the performance of the trackway was acceptable in both areas. The trackway carried 100 cycles of an F-4 load with only small deflection, and the calculated aircraft response values are very similar to those of AM-2.

Because the trackway can be preassembled, its operational advantages over AM-2 are evident. Personnel requirements for the matting teams are reduced by 61 percent and for the total BDR team by 26 percent. Only two loaders are needed to handle the trackway so an extra loader is freed to work at the crater. In addition the total amount of time the loaders are handling the mat is reduced by about 47 percent if the mat can be unrolled from the trailer or by 7 percent if it has to be unloaded first. The cost of the trackway, without including trailers, is reported by the British to be only half that of AM-2 (ref. 7).

The British Class 60 trackway can be incorporated into the AFR 93-2 repair procedure without major changes other than adding the trackway and towing trailers. The total time for the repair of three 750 pound bomb craters will remain the same. The mat assembly does not lie on the critical path of the repair and is completed concurrently with the other tasks of backfilling the crater and placing and grading the select fill; therefore, the overall repair time is not affected.

The Class 60 trackway should replace AM-2 as the repair surfacing in the AFR 93-2 repair procedures. Although AM-2 has slightly better dynamic response and load capacity, these advantages are more than offset by the trackway showing markedly superior utilization of manpower, equipment and money

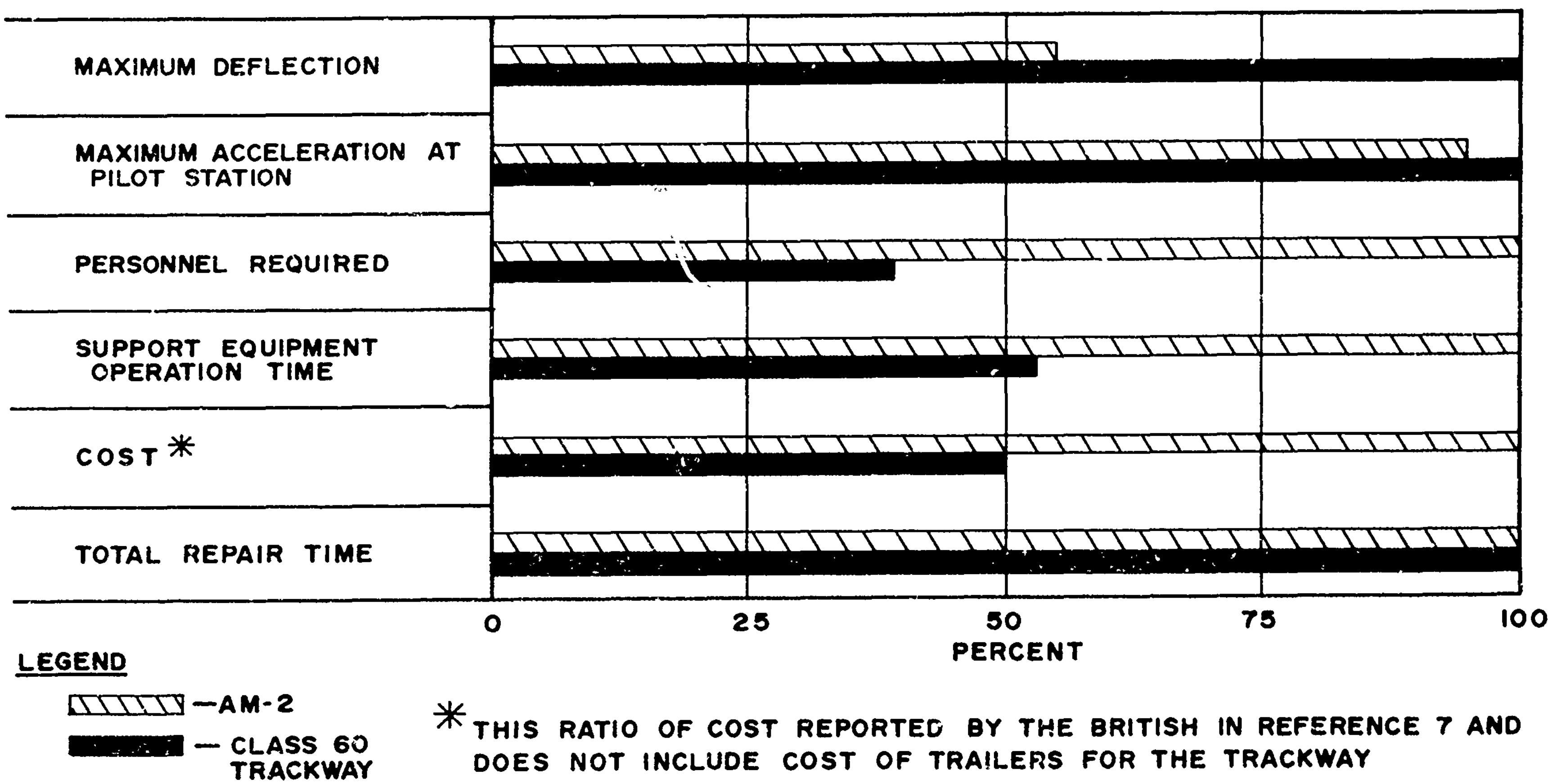


Figure 19. Comparison of AM-2 and Class 60 Trackway

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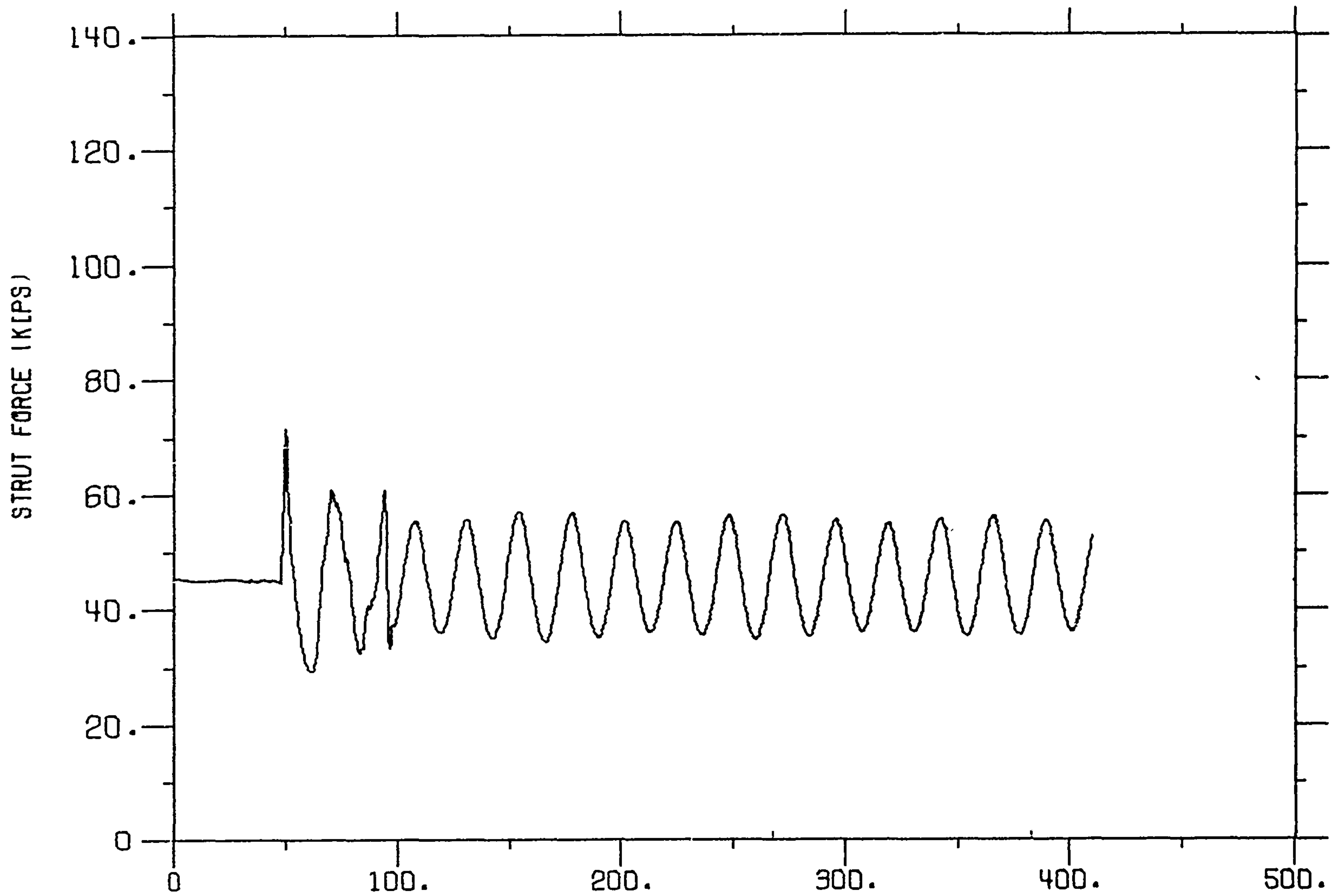
APPENDIX

CALCULATED DYNAMIC AIRCRAFT RESPONSE



F4 BOMB DAMAGE REPAIR PATCH

Figure A1. Main Gear Force, Trackway 1st Pass

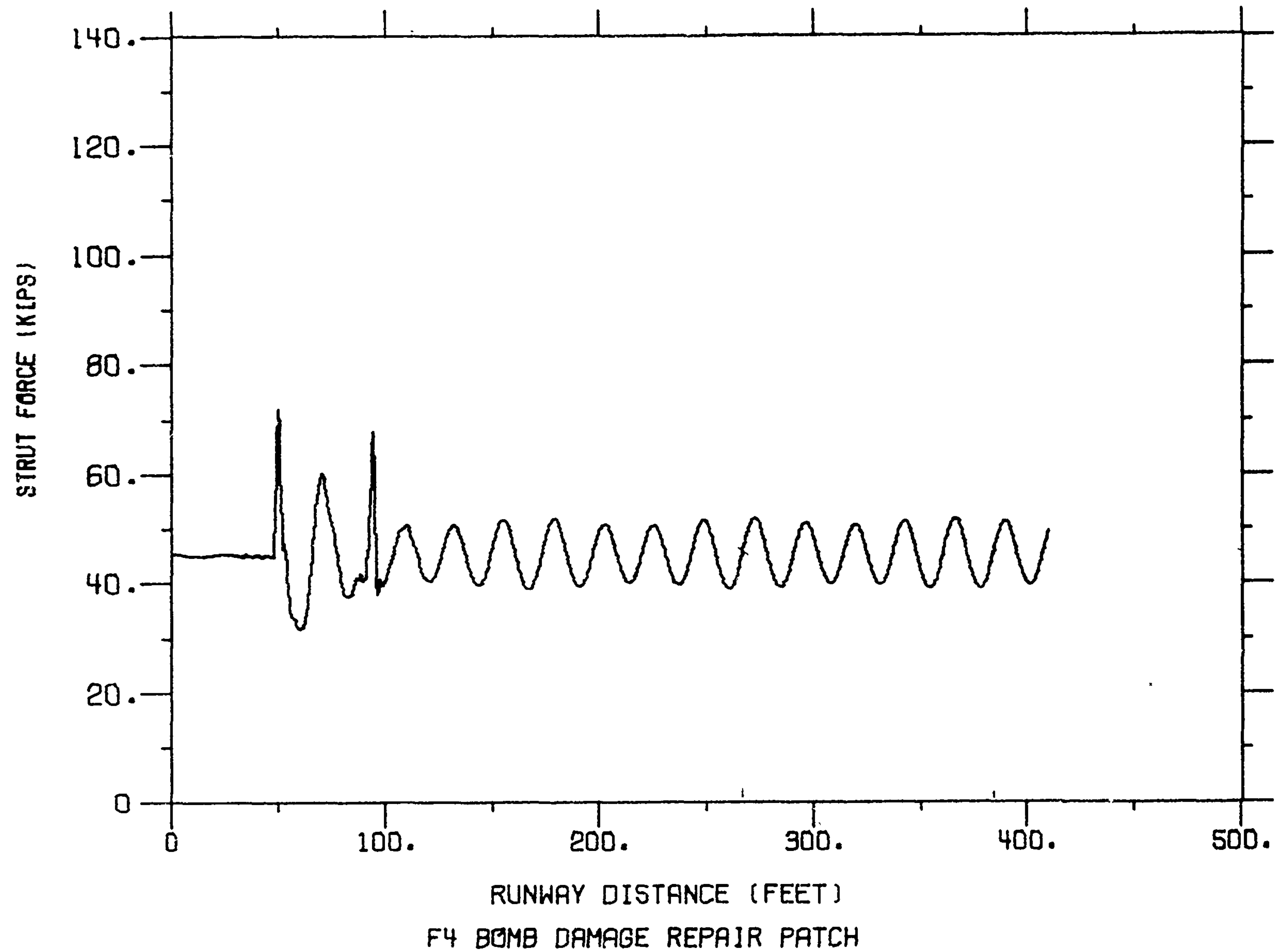


Figure A2. Main Gear Force, Trackway 100th Pass

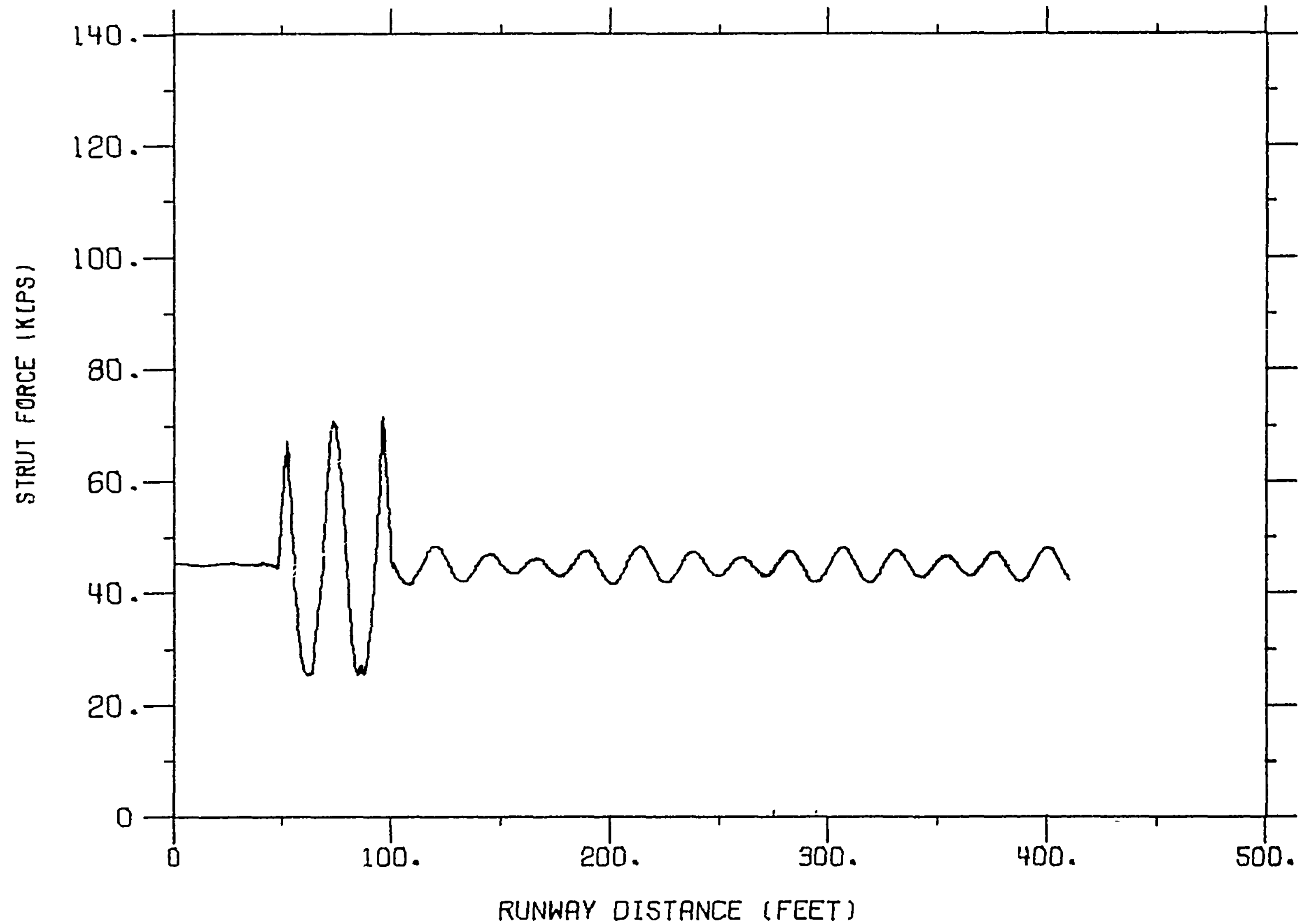
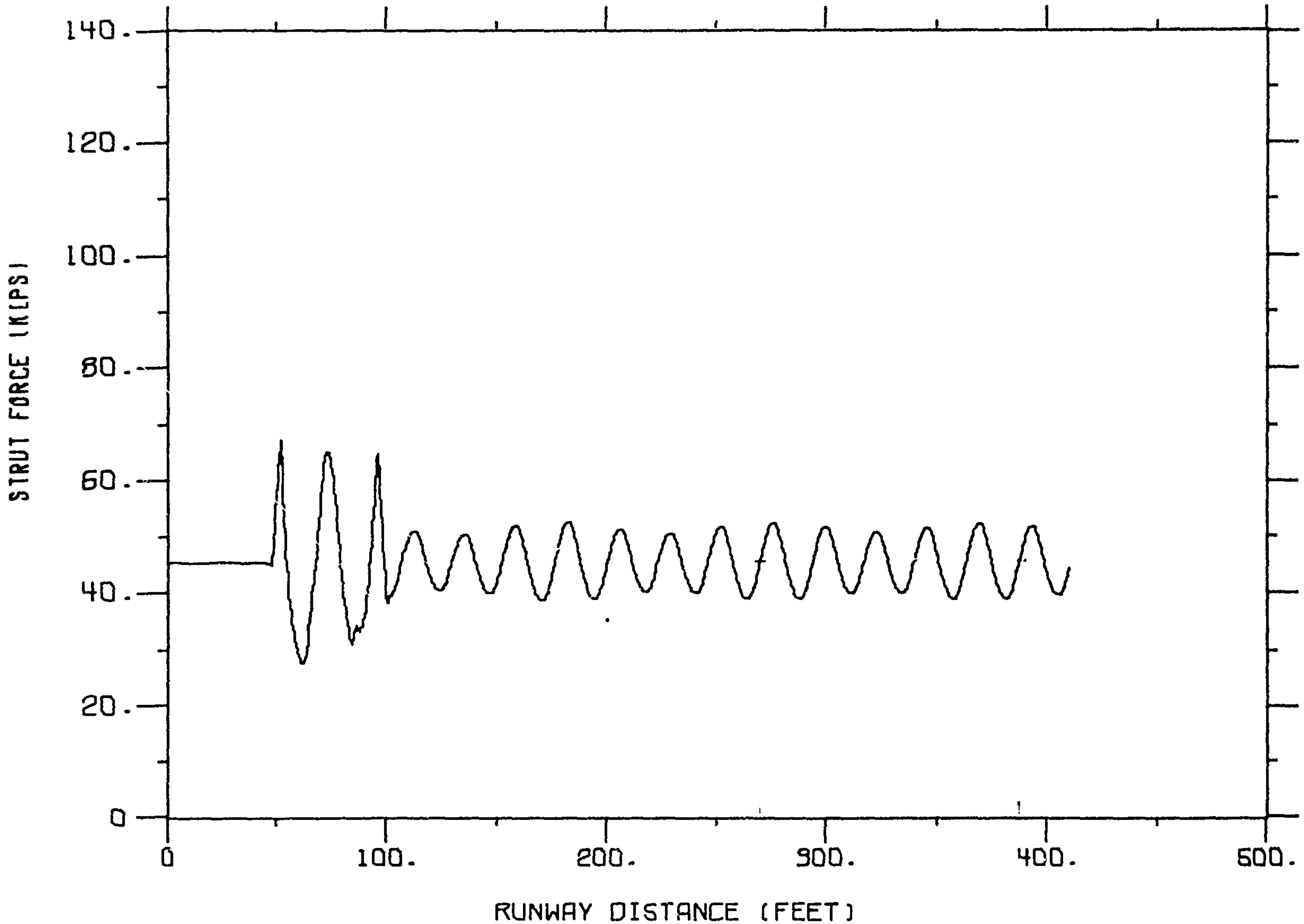


Figure A3. Main Gear Force, AM-2 3rd Pass



F4 BOMB DAMAGE REPAIR PATCH

Figure A4. Main Gear Force, AM-2 100th Pass

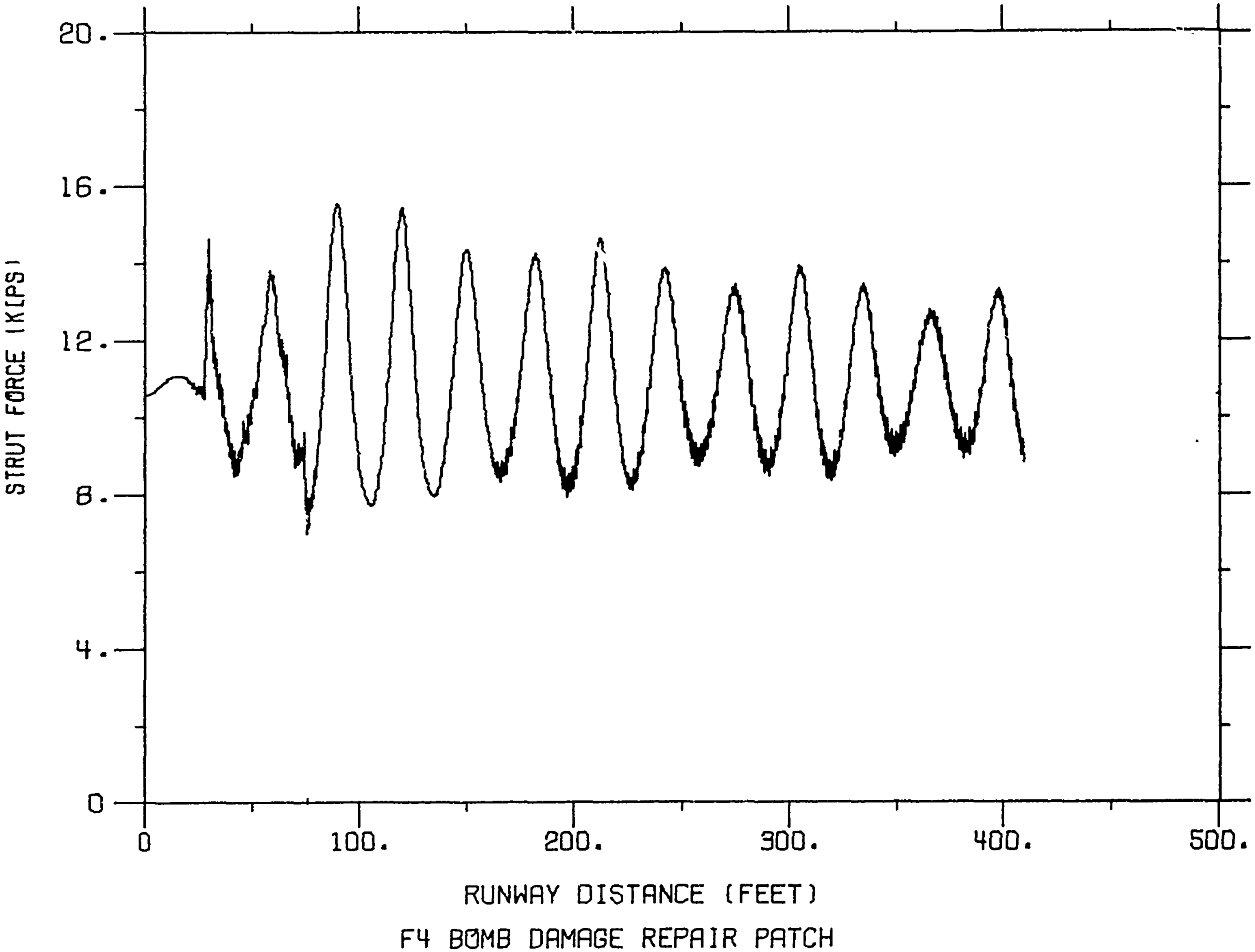


Figure A5. Nose Gear Force, Trackway 1st Pass

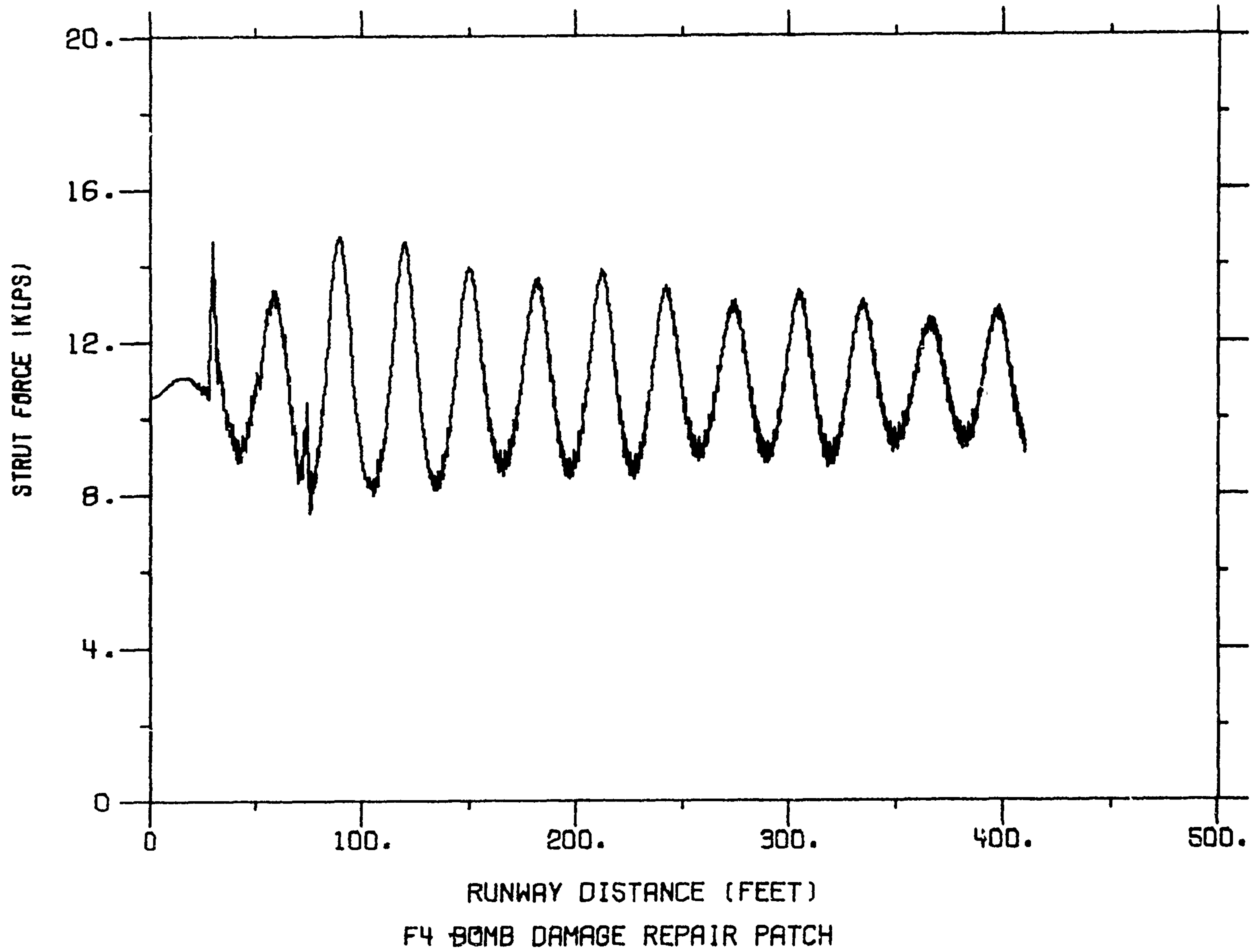
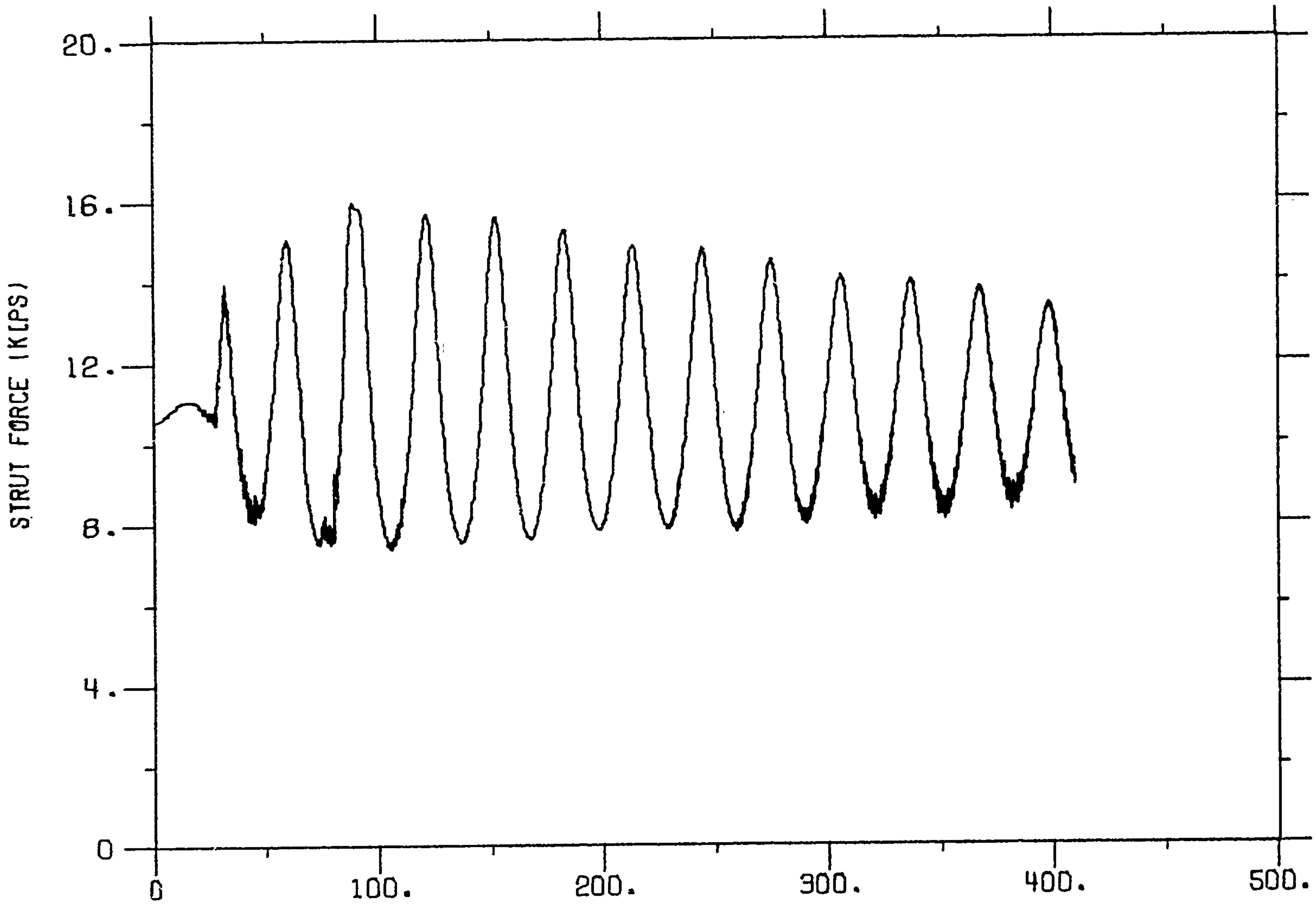
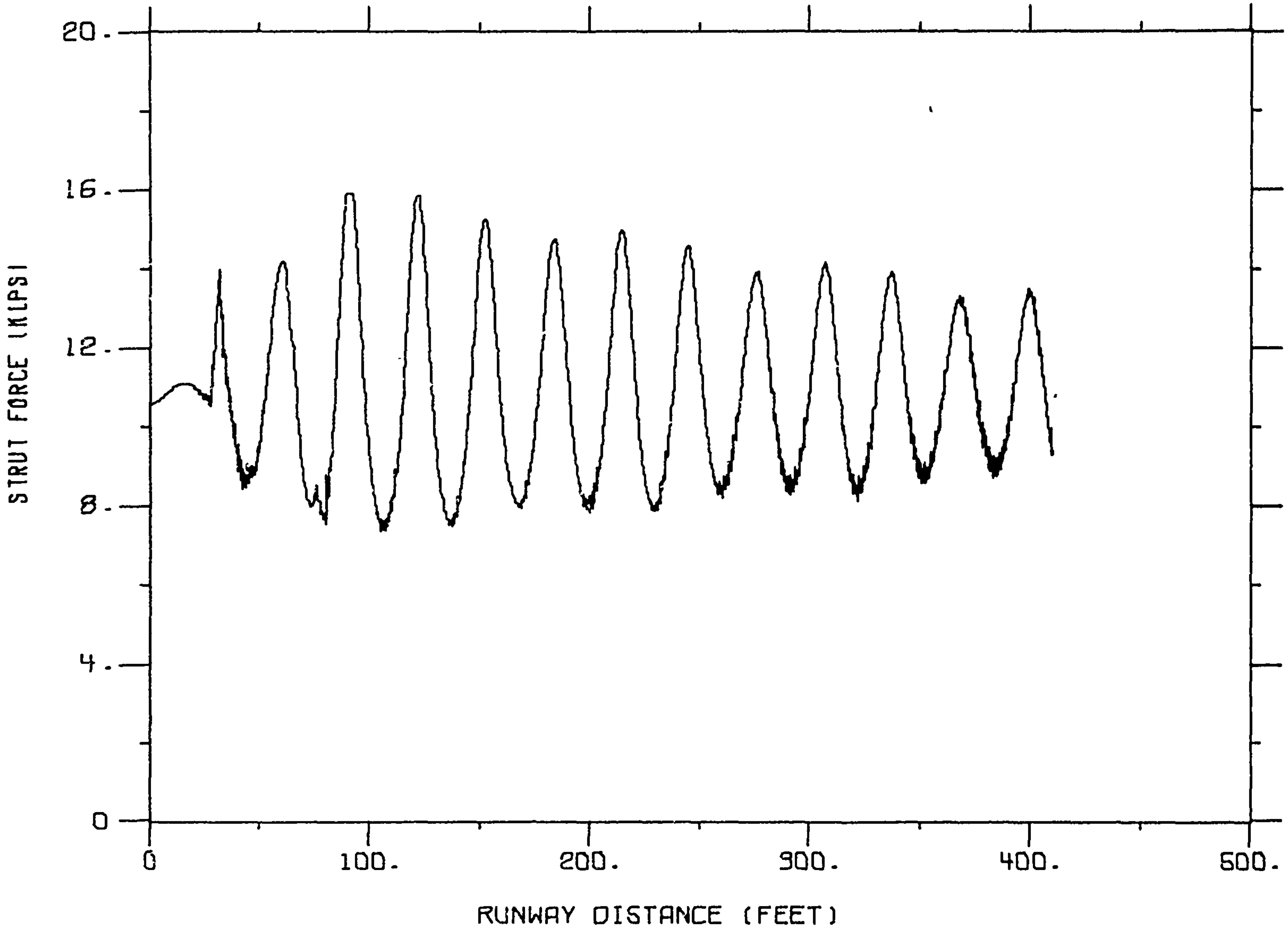


Figure A6. Nose Gear Force, Trackway 100th Pass



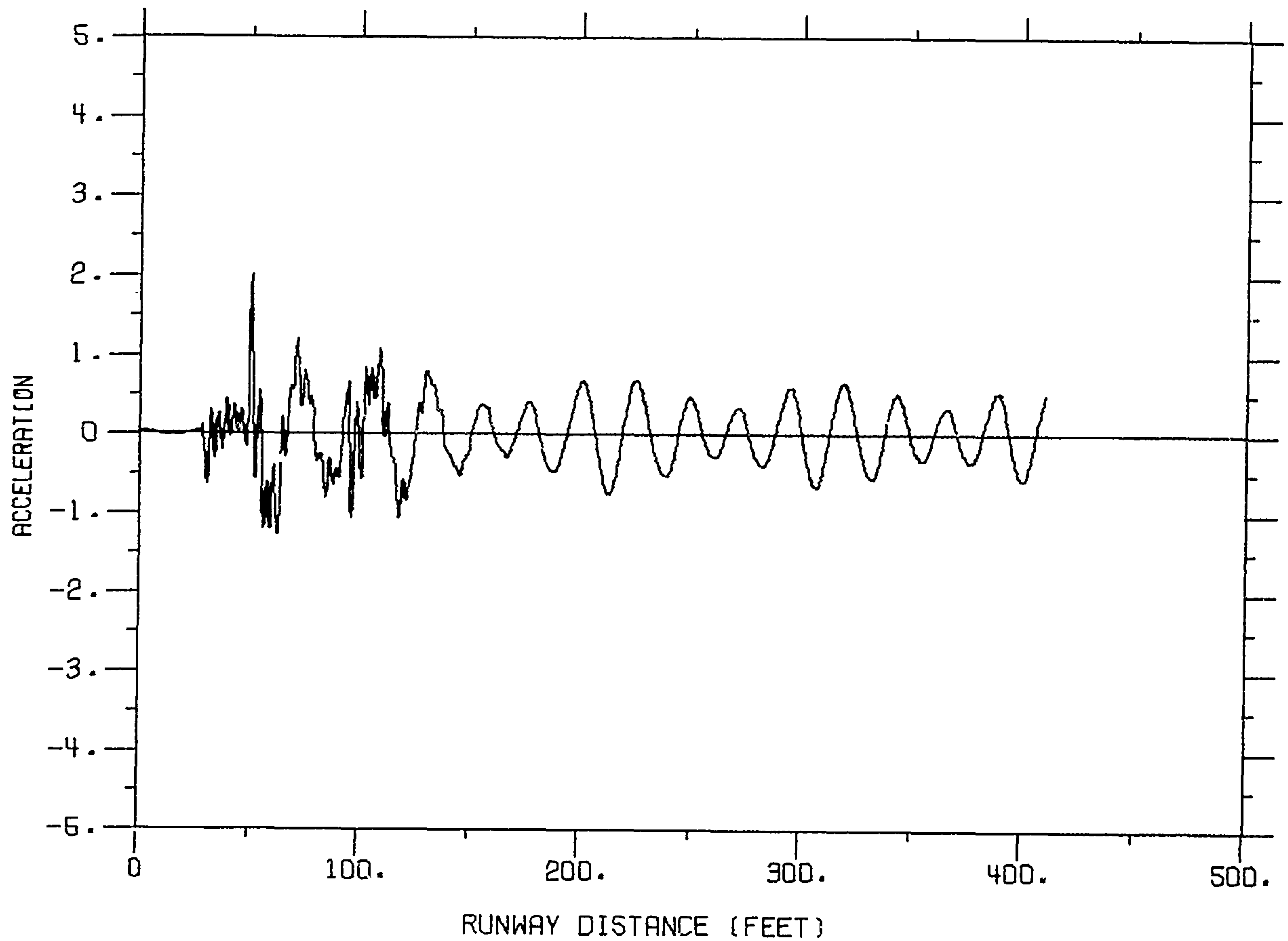
F4 BOMB DAMAGE REPAIR PATCH

Figure A7. Nose Gear Force, AM-2 3rd Pass



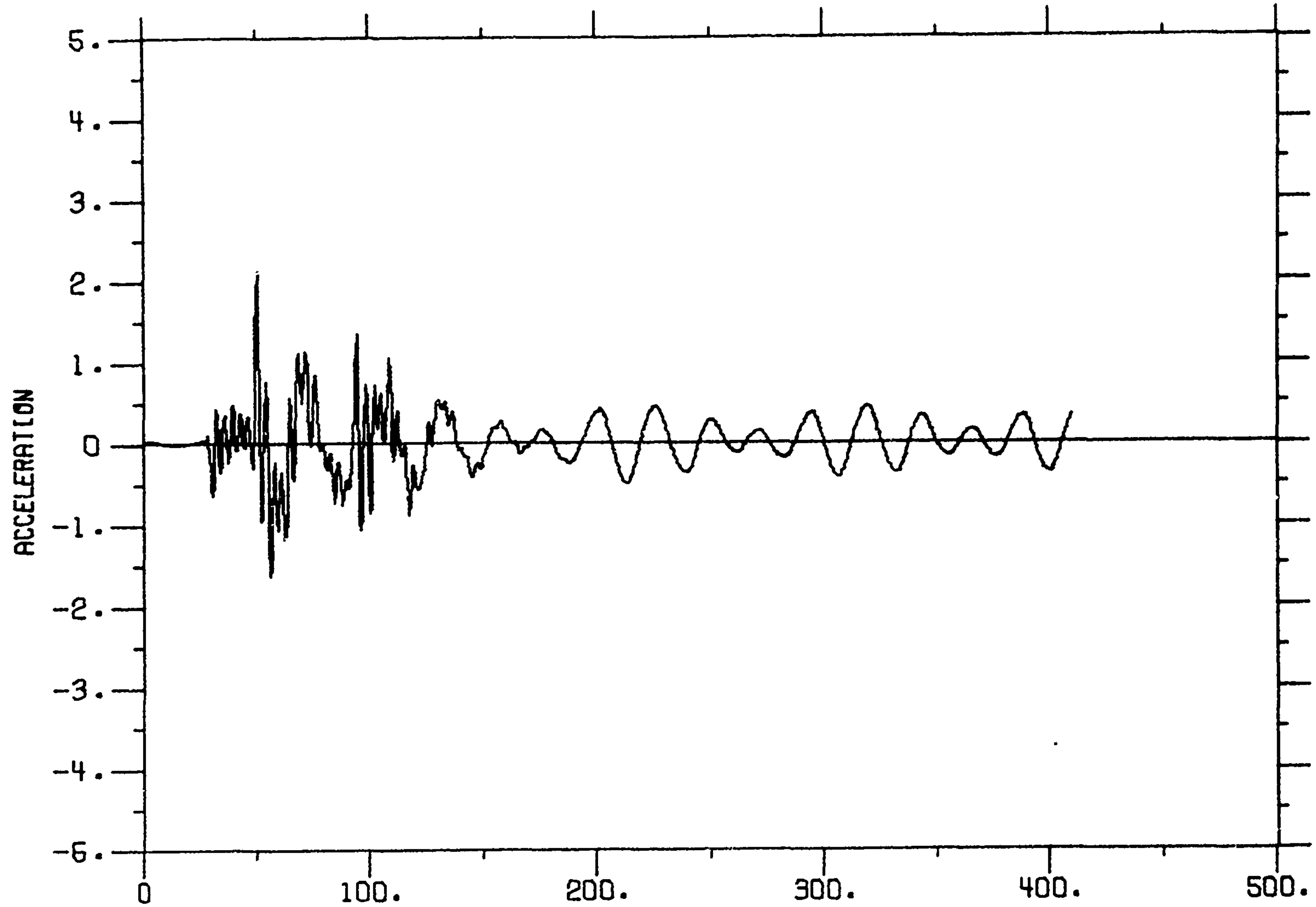
F4 BOMB DAMAGE REPAIR PATCH

Figure A8. Nose Gear Force, AM-2 100th Pass



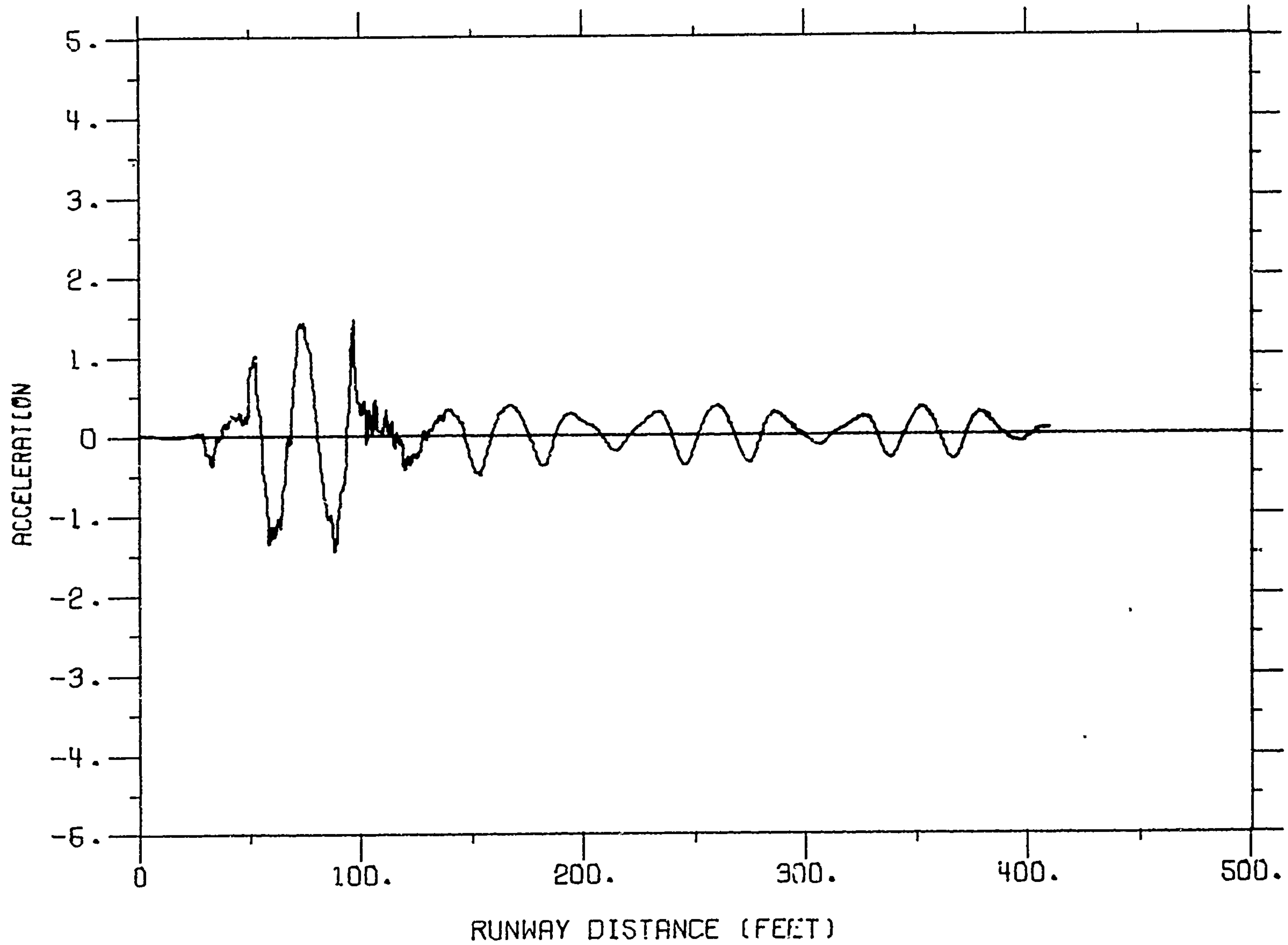
F4 BOMB DAMAGE REPAIR PATCH

Figure A9. Tail Station Acceleration, Trackway 1st Pass



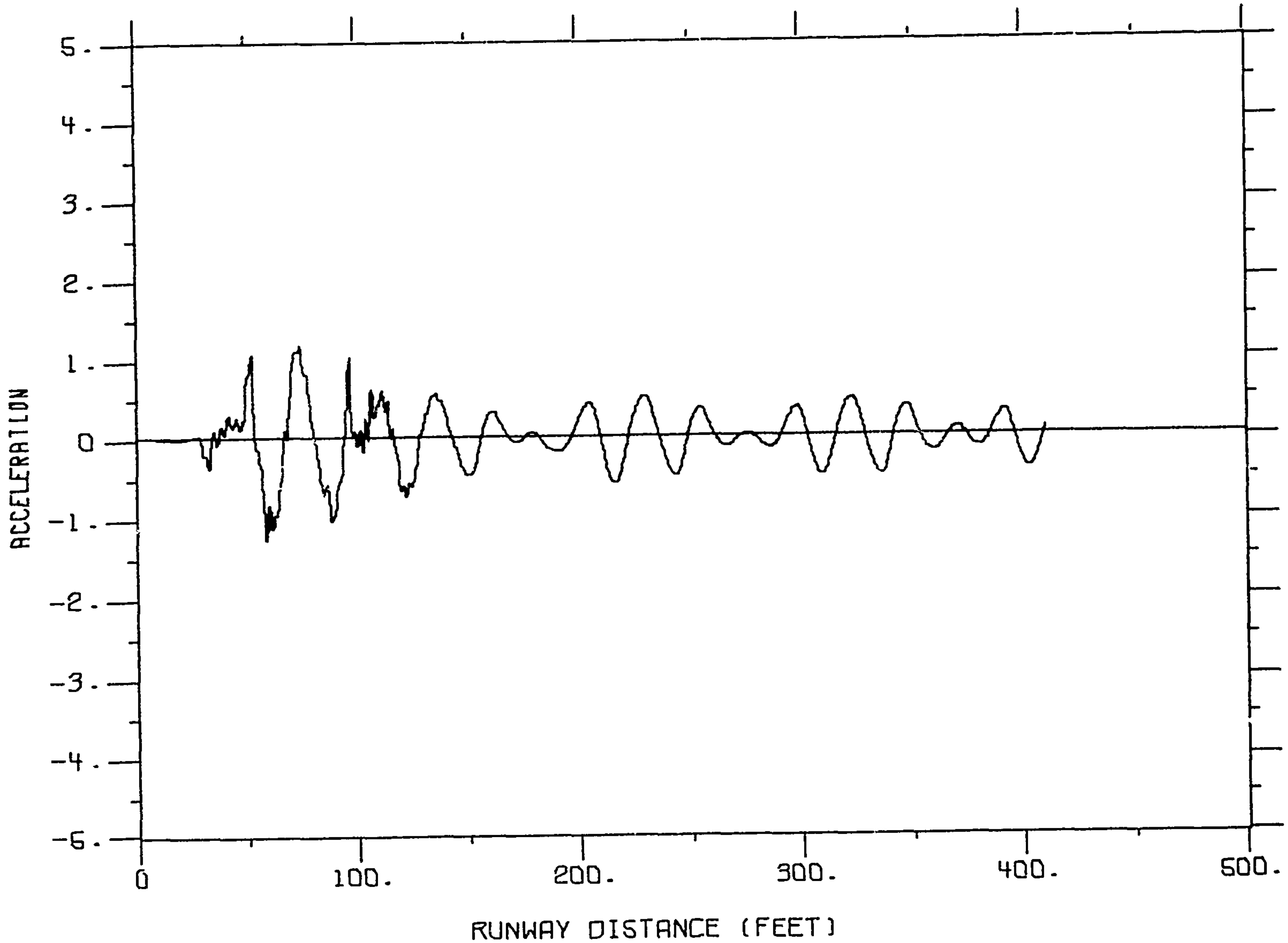
F4 BOMB DAMAGE REPAIR PATCH

Figure A10. Tail Station Acceleration, Trackway 100th Pass



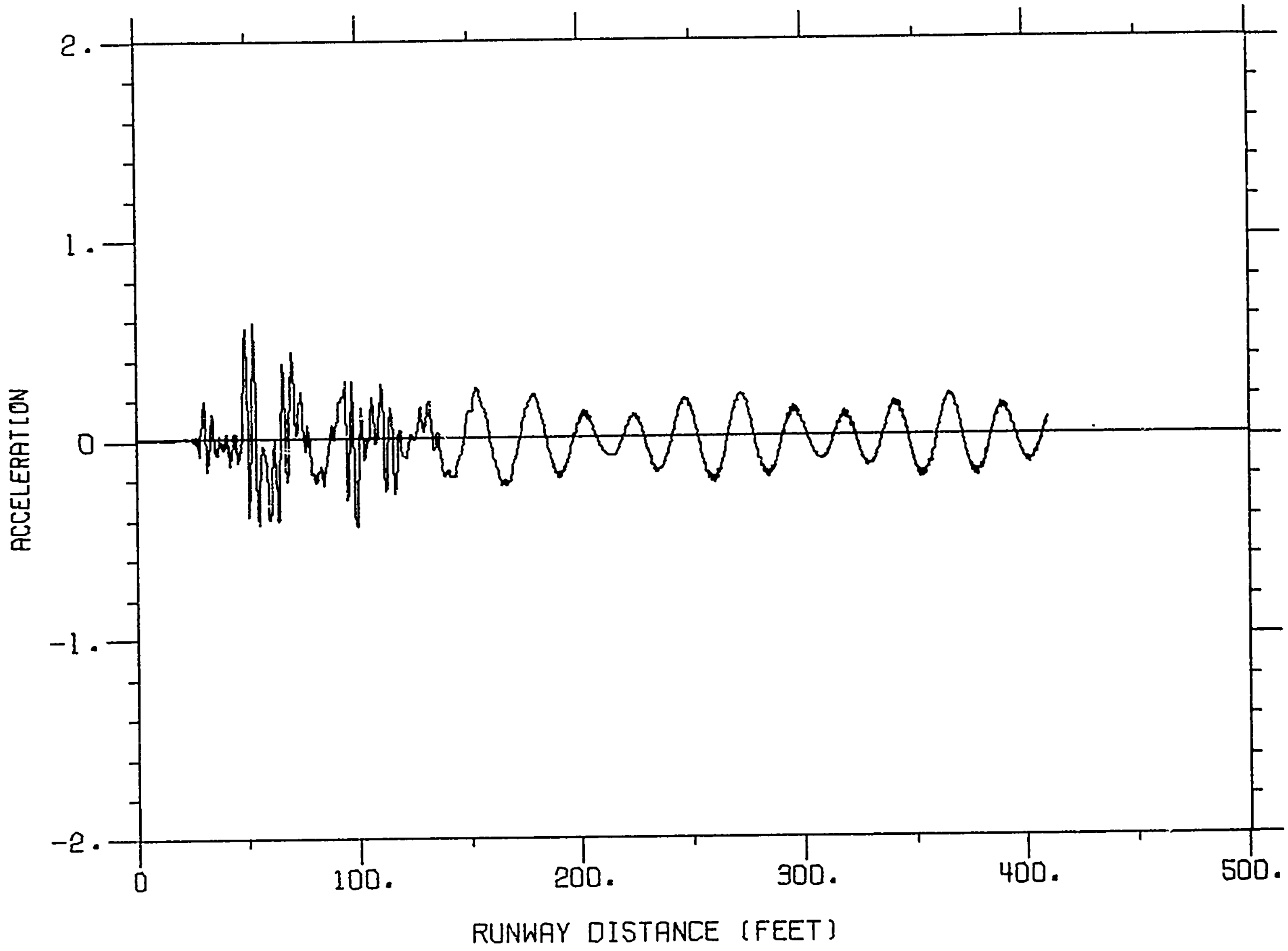
F4 BOMB DAMAGE REPAIR PATCH

Figure A11. Tail Station Acceleration, AM-2 3rd Pass



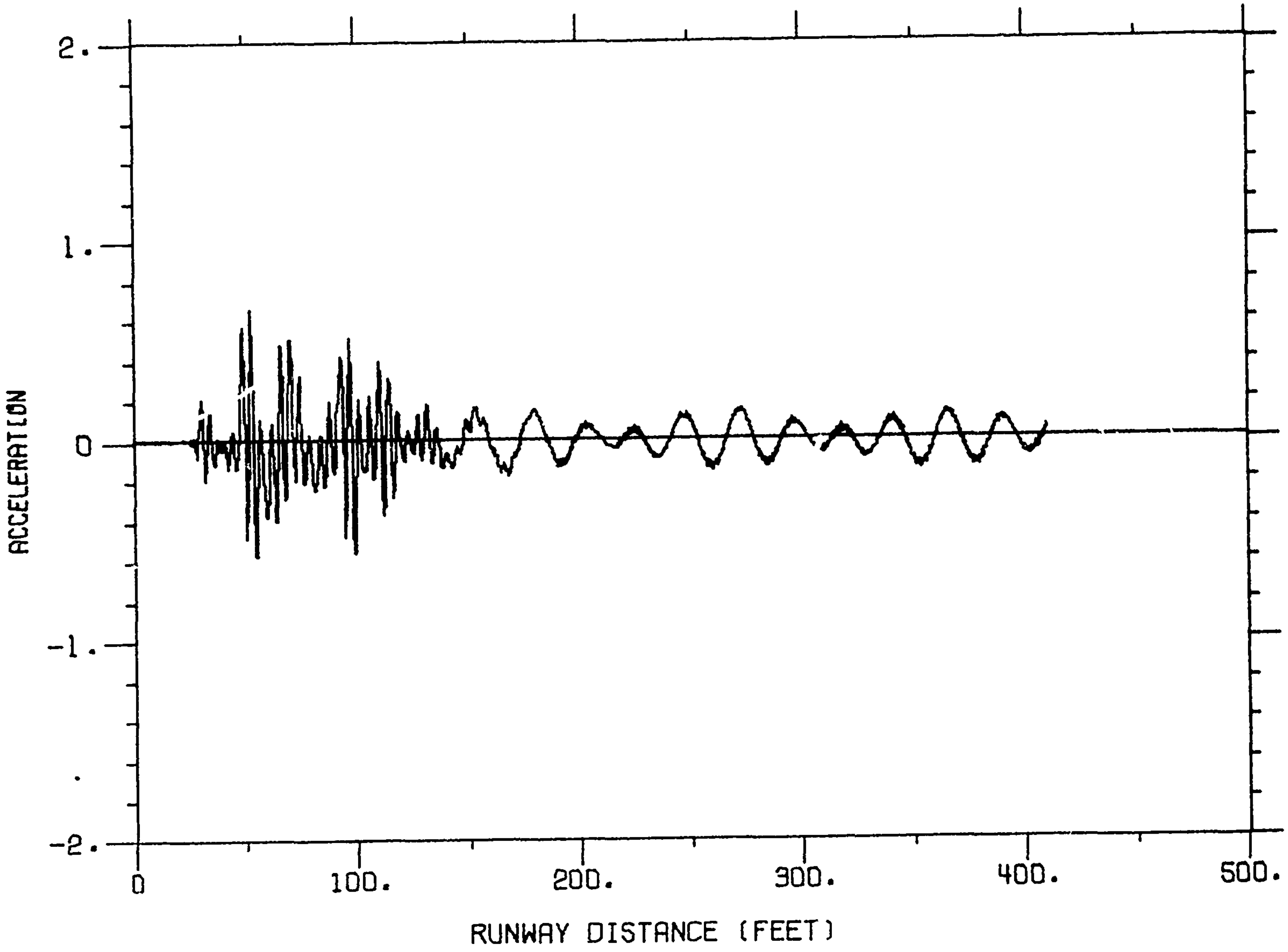
F4 BOMB DAMAGE REPAIR PATCH

Figure A12. Tail Station Acceleration, AM-2 100th Pass



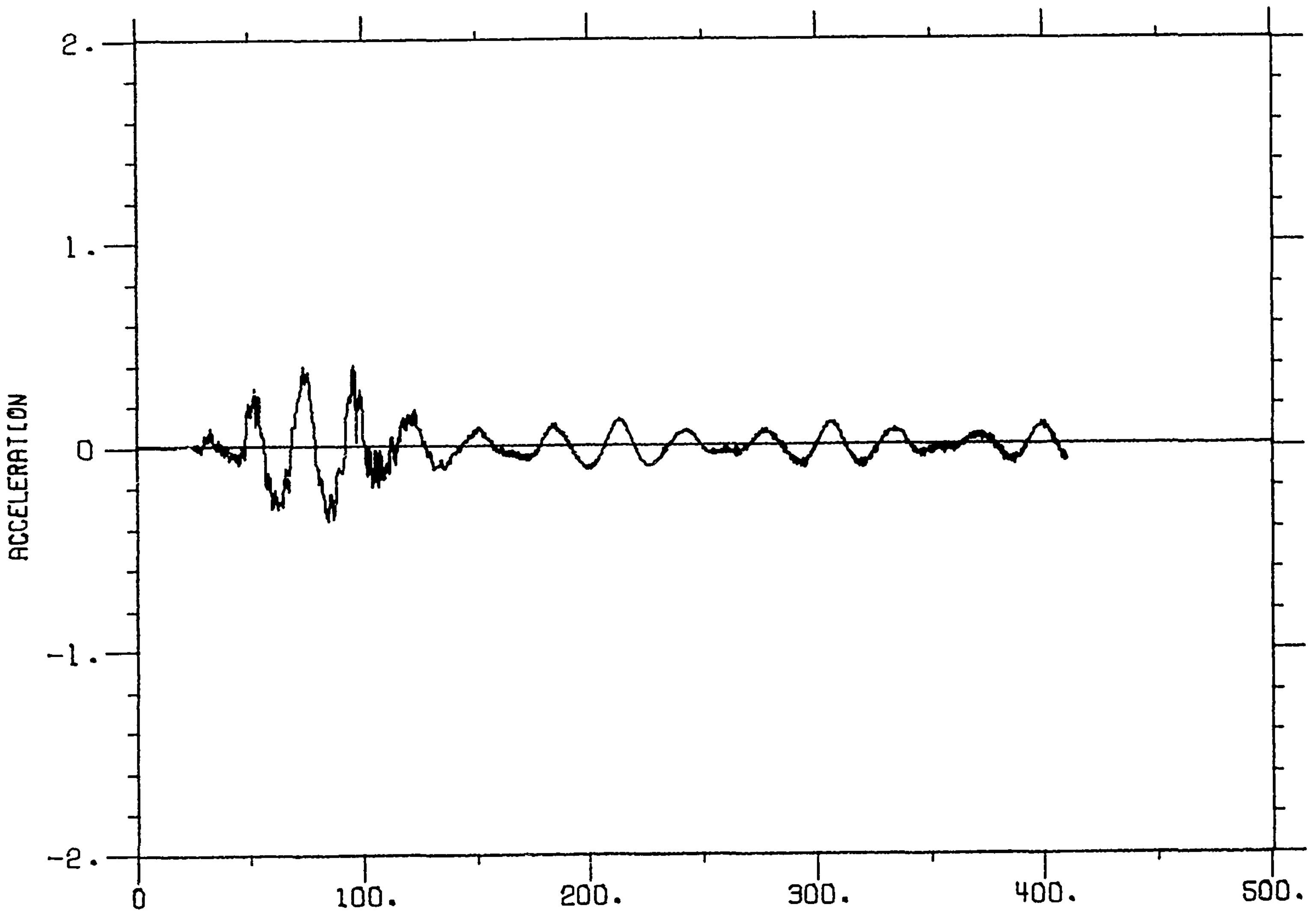
F4 BØMB DAMAGE REPAIR PATCH

Figure A13. Center of Gravity Acceleration, Trackway 1st Pass



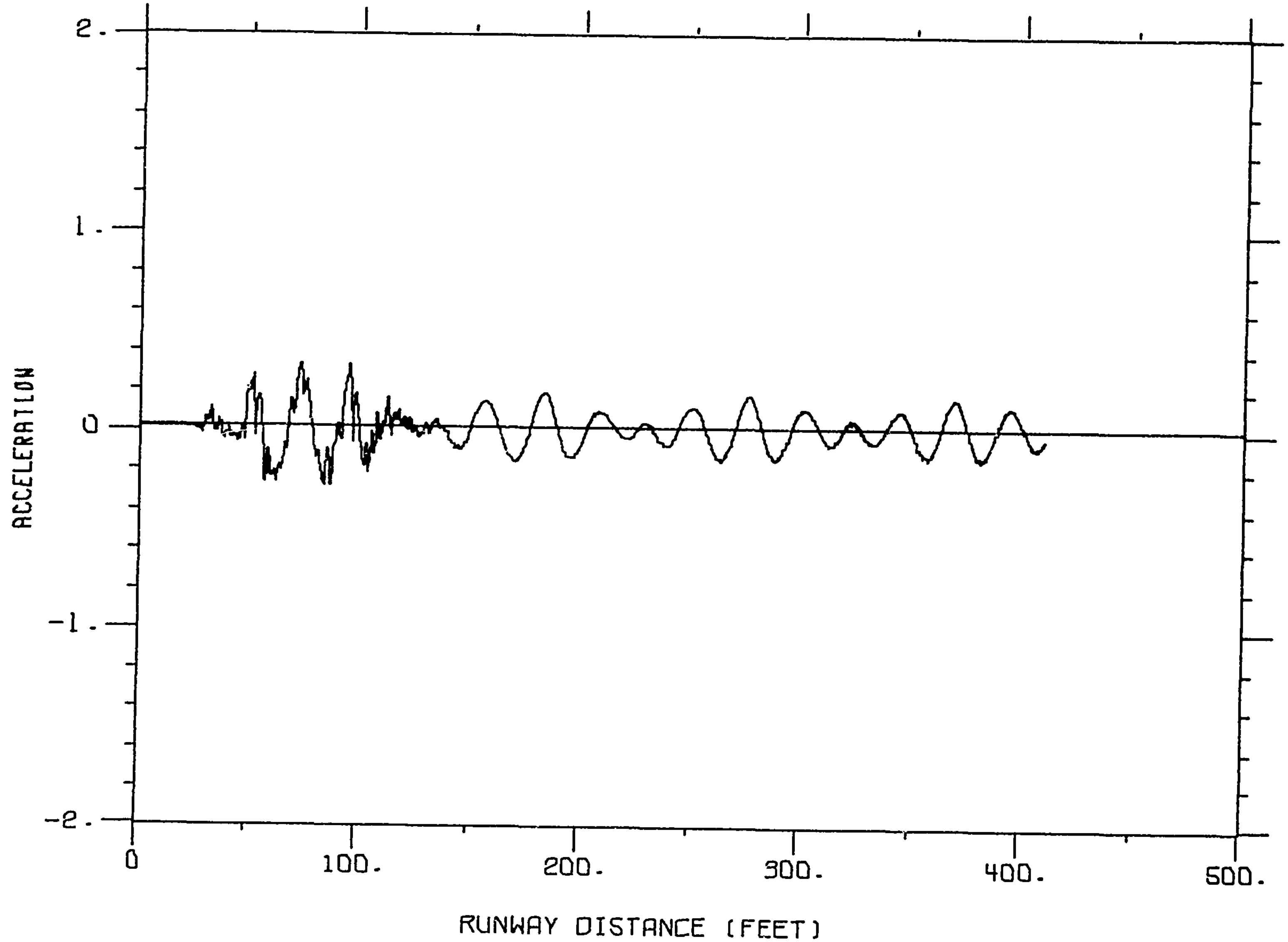
F4 BOMB DAMAGE REPAIR PATCH

Figure A14. Center of Gravity Acceleration, Trackway 100th Pass



F4 BOMB DAMAGE REPAIR PATCH

Figure A15. Center of Gravity AM-2 3rd Pass



F4 BOMB DAMAGE REPAIR PATCH

Figure A16. Center of Gravity AM-2 100th Pass

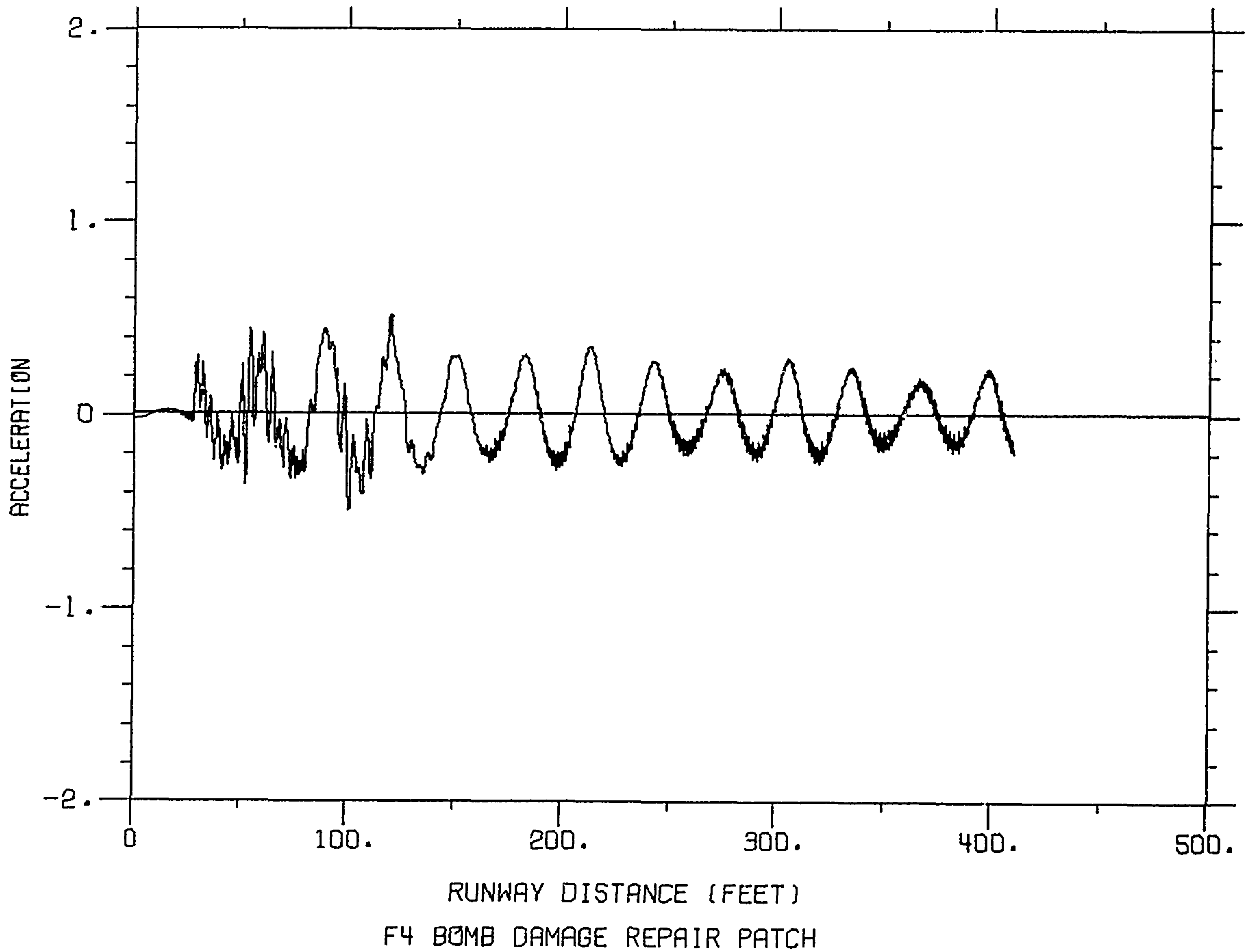


Figure A17. Pilot Station Acceleration, Trackway 1st Pass

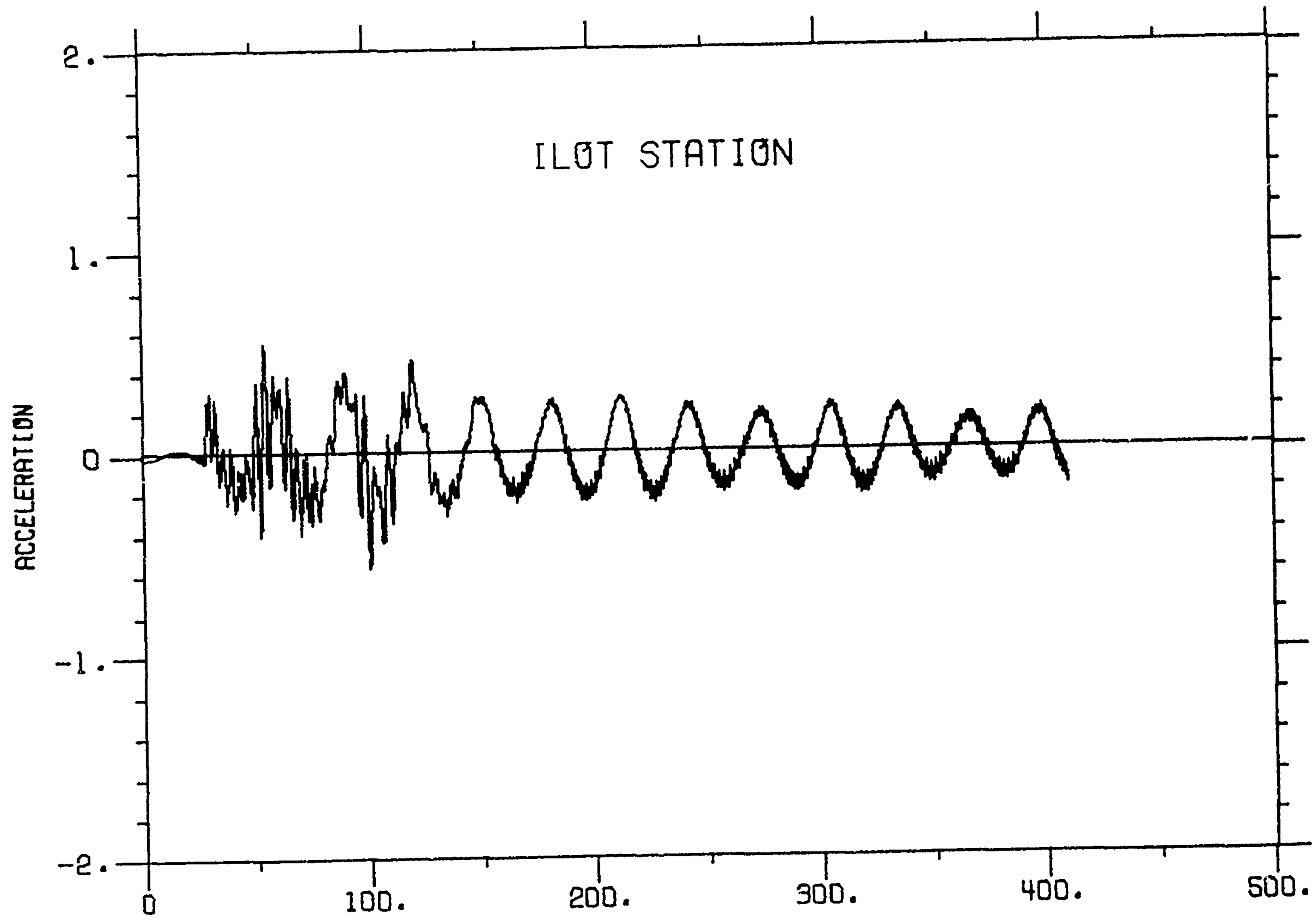


Figure A18. Pilot Station Acceleration, Trackway 100th Pass

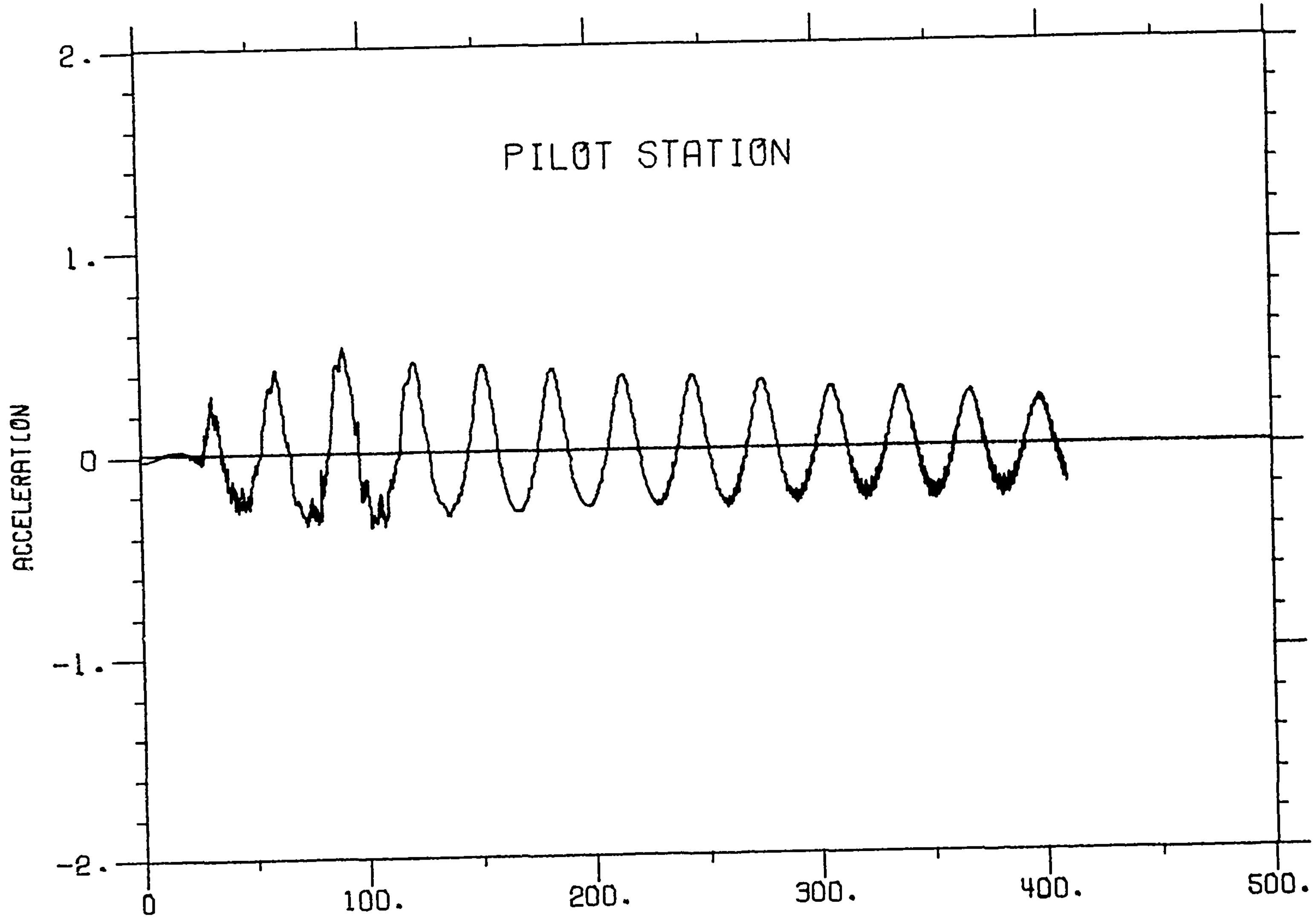


Figure A19. Pilot Station Acceleration, AM-2 3rd Pass

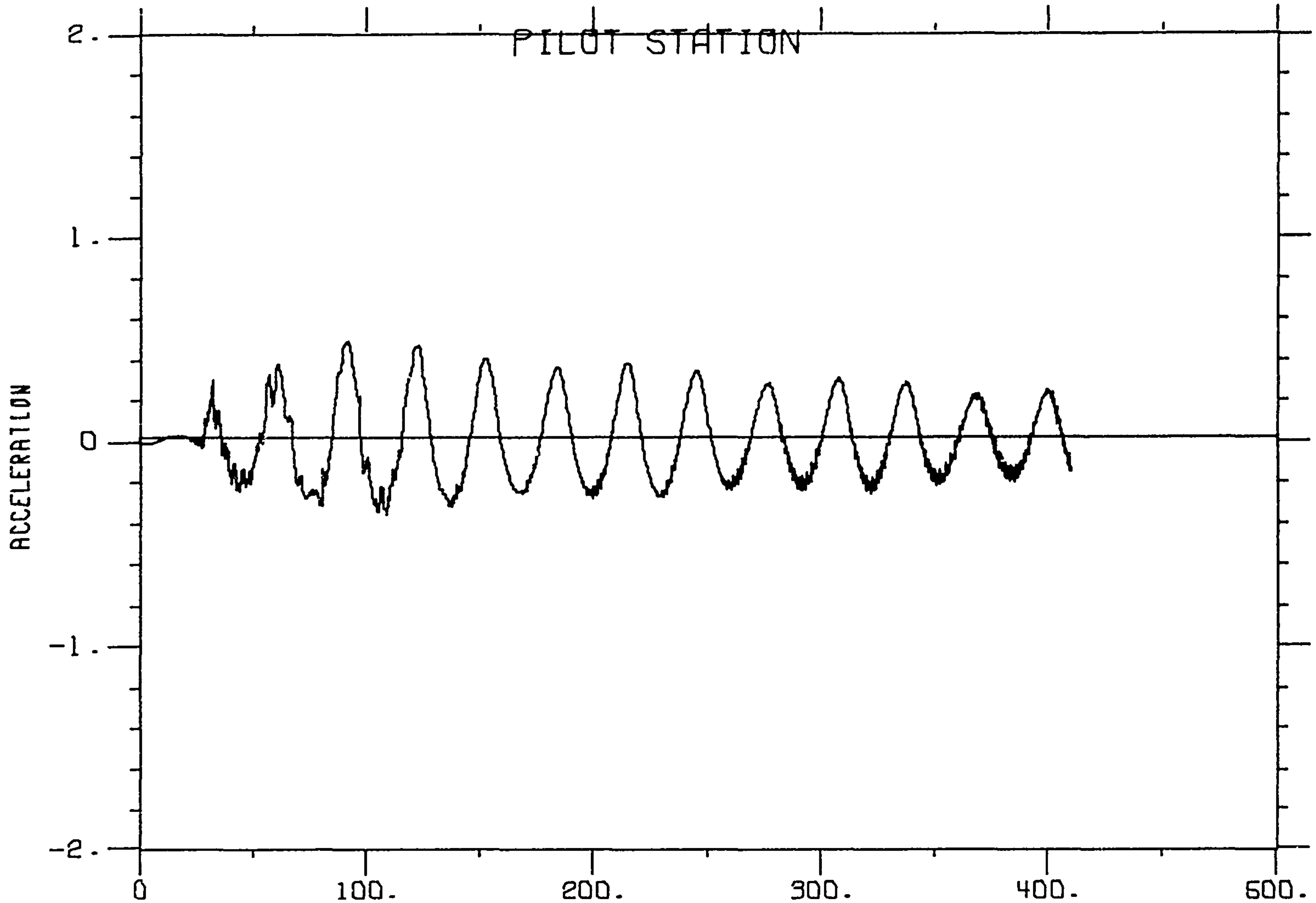


Figure A20. Pilot Station Acceleration, AM-2 100th Pass